# THE OCCURRENCE OF CYPRINIDS AND OTHER SMALL FISH SPECIES IN RELATION TO pH IN ONTARIO LAKES

ONTARIO FISHERIES
ACIDIFICATION REPORT SERIES
NO. 88-14

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1988

Ontario
Ministry of Natural Resources

Vincent G. Kerrio
Minister

89-05975/

ISSN 0832-7629
ISBN 0-7729-4947-6

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Printed in Ontario, Canada

ONTARIO FISHERIES ACIDIFICATION REPORT SERIES

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## ABSTRACT

Data from 426 Ontario lakes that had been intensively sampled for both large and small fish species were used to determine how species number was empirically related to lake area and pH. In lakes with pH $\geq$ 6.0 total number of species increased with lake area, whereas the number of cyprinid species appeared to be unrelated to lake size. As a result, the fraction of total species number comprised of cyprinid species decreased with increasing lake size. Taking the effects of lake size into account, total number of species, total number of cyprinid species, and cyprinid fraction decreased with pH below pH 6.0. An augmented lake set of 488 lakes which had been intensively sampled for small fish species was used to examine the potential of the 13 most common small species as early indicators of changes in the fish community due to acidification. The most promising species were: fathead minnow (Pimephales promelas), common shiner (Notropis cornutus), bluntnose minnow (Pimephales notatus), blacknose shiner (Notropis heterolepis),and slimy sculpin (Cottus cognatus).

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# INTRODUCTION

Many common small fishes, especially members of the family Cyprinidae, are highly sensitive to acidic water (Rahel and Magnuson 1983; Eilers et al. 1984; Magnuson et al. 1984; McNicol et al. 1987), and therefore are expected to play a substantial role in the observed decline of total species richness with decreasing pH (Rago and Wiener 1986; Matuszek and Beggs 1988). These relatively short-lived smaller species tend to exhibit more rapid and detectable population changes in response to acidification than longer lived larger species (Mills and Schindler 1986; Mills et al. 1987), making them useful early warning indicators of changes in the fish community due to acidification.

We have compiled data from a number of sources on a relatively large set of Ontario lakes (N = 488) which have been intensively surveyed for small fish species. A majority of these lakes (N = 426) have been intensively sampled for all fish species, both large and small. Using this data set we first examine the relationships between total number of fish species and the variables lake area and pH. This has been done previously for Ontario lakes by Matuszek and Beggs (1988), but with a less intensively sampled lake set. Next we examine the number of cyprinid species in relation to lake area and pH and describe how the ratio of cyprinid species to total species changes with lake

area and pH. Finally we focus on the individual species of small fish, mostly cyprinids, that are most common in acid-sensitive lakes (alkalinity < 10 mg/l) in Ontario. We examine the differences between lakes in which a particular species is found compared with those in which it is absent, and assess the utility of each species as an early indicator of acidification stress in the fish community.

# METHODS

## DATA BASE DESCRIPTION

The 488 sampled lakes are located in Ontario between 44 and 50 N Lat (Fig. 1), in a region where the wet deposition of sulphate ranges from < 10 kg/ha/yr (northwest) to > 30 kg/ha/yr (southeast) (Tang et al. 1986). Species data were compiled from three main sources: the Ontario Ministry of Natural Resources (OMNR), the Canadian government, and the University of Toronto. Within the OMNR, data were supplied by fisheries assessment units (Algoma, Algonquin Park, Haliburton-Hastings, Quetico-Milles des Lacs, and Rideau Lakes) (N = 45), the Fisheries Acidification Program (comparative lakes study - Sudbury, trend through time study - Dorset, and the neutralization study - Sudbury and Parry Sound) (N = 88), and the Fisheries Research Section (N = 66). The federal government data were obtained from the Experimental Lakes Area (ELA) study in northwestern Ontario (N = 98), and a Canadian Wildlife Service (CWS) study of small headwater lakes in central Ontario (N = 62) (McNicol et al. 1987). The University of Toronto data are from lakes in the La Cloche Mountain area near Sudbury (N = 56) (Harvey 1982), lakes near Wawa (N = 30) (Somers and Harvey 1984), and lakes on Manitoulin Island (N = 43) (Harvey 1978). Lakes in the Sudbury and Wawa areas have been impacted by $SO_2$ emissions from local smelters

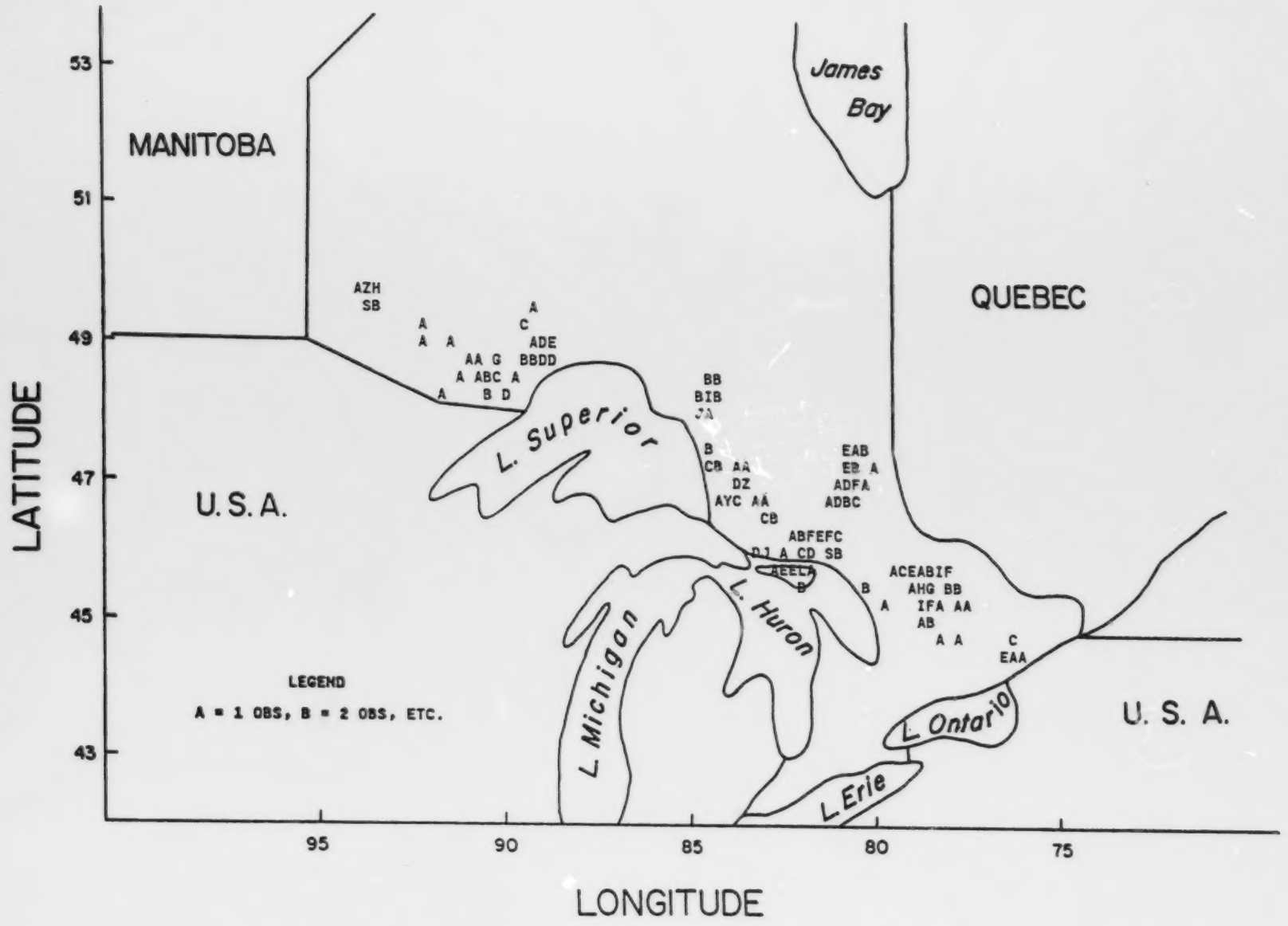


FIGURE 1. Location of surveyed lakes in Ontario.

(Somers and Harvey 1984; Keller and Pitblado 1986).

A variety of gear was used to sample the fish species in the amalgamated set of lakes, including gill nets, trap nets, seine nets, dip nets, and minnow traps. Sampling was done between 1972 and 1987. All lakes, except those in the CWS study, were judged to have been sampled intensively for both small and large fish species. Only small species were sought in the CWS survey, thereby preventing the use of those lakes in analyses involving total number of fish species.

Wherever possible, the extensive lake survey of the Fisheries Acidification Program of the OMNR (Green et al. 1987) was used to provide chemical and physical data for the lakes with fish species data. If chemical and physical data were not available from this data base, the information was generally obtained from the same sources as the species data (Harvey and Coombs 1971; Harvey 1975; Beamish et al. 1976; Harvey and Lee 1980; Somers 1980; Fraser 1981; Bendell et al. 1983; Schindler and Rushcynski 1983; Stewart 1983; Somers and Harvey 1984; Booth et al. 1987).

Chemical sampling was done between 1970 and 1986, mainly in the summer, fall, and winter. Either surface or tube composite samples were taken. Water samples were analyzed in the field or at central laboratories. pH was measured with electronic pH meters; alkalinity by

titration for the inflection point. Aluminum was measured as the total concentration of all forms. The morphoedaphic index (MEI), an index of the productivity of a lake (Ryder et al. 1974), was calculated from conductance and mean depth (Dodge et al. 1985). Plots of available chemical data were used to identify lakes (outliers) with unusually high values of aluminum, iron, sulphate, or manganese. These were assumed to be impacted by local industry and omitted from our lake set.

In many cases the dates for species and chemical sampling did not coincide. However, of the 414 lakes with both dates recorded, 78% had sampling dates two or less years apart. The largest discrepancy was eight years. When low pH lakes (< 5.8) are considered, 91% of lakes with both sampling dates recorded had a discrepancy of two years or less. In the Sudbury area Keller and Pitblado (1985) found that low pH (< 5.5) lakes increased by an average 0.3 pH units over 5 to 7 year periods after 1970, following reductions in $SO_2$ emissions from local smelters. In lakes remote from $SO_2$ sources like Sudbury, there is little evidence of significant changes in pH over the time periods in question (Dillon et al. 1987). Therefore, we judged that any errors in pH due to differences in sampling dates would not be large enough to warrant eliminating the data.

In the Sudbury area the observed number of species may be abnormally low as a result of earlier, harsher conditions (eg. lower pH) associated with higher local smelter emissions (Keller and Pitblado 1986). To test this hypothesis, a comparison was made between plots of species number by pH for recently sampled ($\geq$ 1981) low-pH lakes near Sudbury and similar lakes remote from Sudbury. There was no indication that an adjustment to the pH values of the Sudbury lakes was needed.

## DATA ANALYSIS

To eliminate any possible confounding effects associated with low pH, only high-pH (> 6.0) lakes were used to determine the relationship between total species number and lake area. Matuszek and Beggs (1988) have reported that total species number declines with pH below pH 6.0 in Ontario lakes. Our surveyed lakes were grouped by lake area interval (0.2 unit on the $\log_{10}$ scale) and the mean number of fish species was calculated for each group. A log-log relationship between mean number of fish species and lake area interval provided the best fit of the data. However, lakes with area < 10 ha did not fit the model. The mean number of species in these lakes was lower than expected. Almost all of the surveyed lakes < 10 ha were located in northwestern Ontario (part of the ELA study) where climatic and geographic factors may limit total species number. These lakes (N = 50) were eliminated from subsequent development of a species number - lake area relationship. A regression of mean number of species on lake area interval (weighted by the reciprocal of the variance of the mean) fitted the data well (r = 0.95), but a plot of residuals for individual lakes indicated that the regression equation predicted values that were too high. Therefore, instead of using means, the relationship was quantified by regressing $\log_{10}$ total species number on $\log_{10}$ lake area for individual lakes with pH $\geq$ 6.0 and area $\geq$ 10 ha.

The relationship between total species number and pH, independent of effects associated with lake area, was determined by first using the regression equation between total species number and lake area to calculate the expected number of species in each lake. Then the mean of the differences between expected number of species and observed number of species (mean residual) was calculated for each pH interval (0.2 unit) and plotted. Only means based on five or more lakes are presented in the figures.

Methods similar to those used for total species number were applied to cyprinid species number and the ratio of cyprinid species number to total species number, to examine their relationships with lake area and pH.

To determine which small fish species could be useful as early indicators of community changes due to acidification, we first identified the small fish species that were most common in the subset of acid-sensitive lakes (Fig. 2). We selected lakes with alkalinity < 10 mg/l because they are considered to be at least moderately sensitive to acidic deposition (United States - Canada 1981; Ontario Ministry of the Environment 1982). Lakes which lacked an alkalinity value were considered acid-sensitive if their pH was < 6.5 (N=70). A plot of alkalinity versus pH indicated that lakes with pH < 6.5 (N=149) generally had an

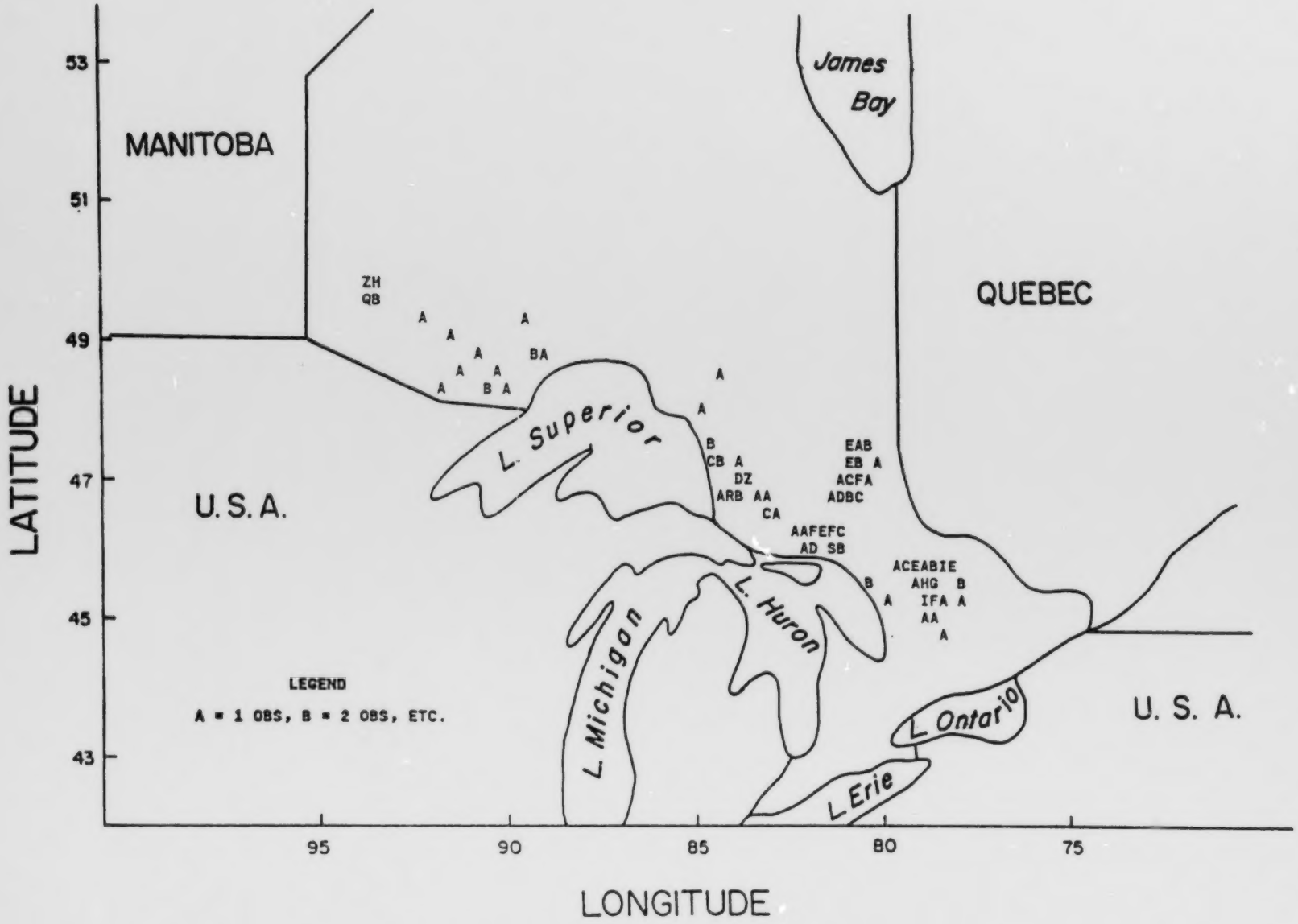


FIGURE 2. Location of surveyed acid-sensitive lakes (alkalinity < 10 mg/l) in Ontario.

alkalinity value < 10 mg/L (99.3%).

The lake type inhabited by each of the most common small fish species was identified by comparing selected chemical, physical, and biotic attributes of the acid-sensitive lakes in which the species was present with those of the acid-sensitive lakes in which the species was absent. Comparisons were restricted to northwestern Ontario (Long > 87) or south-central Ontario (Long < 87) if the species distribution was limited to one of these regions. A list of the selected variables, with accompanying descriptive statistics for the set of acid-sensitive lakes, is given in Table 1. The variable, number of species, is the total number of fish species found in a lake and is only recorded for lakes with pH $\geq$ 6.0, so that the negative effects associated with low pH are not present. Since most of the variables did not have normal distributions, transformations ($\log_{10}$ and square root) were applied to try to increase normality and facilitate comparisons between the lake sets in which each species was present and absent. Constants were added as necessary to allow the transformation to be performed. T-tests were used to test for differences between inhabited and uninhabited lakes. When variances were unequal an approximate t statistic was calculated (SAS Institute Inc. 1982). However, because parametric tests can be unreliable when the assumptions of normality are violated, non-parametric Wilcoxon rank sum tests were also calculated.

**Table 1. Chemical, physical and biotic variables used to characterize lakes inhabited by each of the most common small fish species. The descriptive statistics are for the set of surveyed acid-sensitive lakes.**

| Variable | Mean | Median | Range | N | Skewness |
|---|---|---|---|---|---|
| pH | 6.0 | 6.1 | 3.8 - 7.4 | 332 | -0.57 |
| Alkalinity (mg/L) | 3.1 | 2.8 | -2.7 - 10.0 | 262 | 0.55 |
| Calcium (mg/L) | 2.6 | 2.4 | 0.2 - 7.0 | 313 | 0.78 |
| Aluminum (ug/L) | 98 | 68 | 1 - 740 | 171 | 2.52 |
| Dissolved Organic Carbon (DOC) (mg/L) | 5.8 | 4.4 | 0.4 - 21.2 | 194 | 1.17 |
| Latitude (degrees) | 47.3 | 46.9 | 44.7 - 49.8 | 332 | 0.53 |
| Lake Area (hectares) | 156.6 | 26.2 | 0.9 - 6510.0 | 322 | 8.21 |
| Maximum Depth (m) | 22.3 | 19.0 | 1.0 - 87.5 | 223 | 1.08 |
| Mean Depth (m) | 8.8 | 7.6 | 0.7 - 29.8 | 172 | 1.17 |
| Elevation (m) | 345 | 360 | 188 - 534 | 168 | -0.22 |
| Morphoedaphic Index (MEI) (mg/L/m) | 5.2 | 3.3 | 0.6 - 29.5 | 151 | 2.49 |
| Number of Fish Species (Lakes with pH $\geq$ 6.0) | 8.6 | 8.0 | 1 - 27 | 141 | 1.03 |

The tolerance of each species to acidic water was determined by plotting the pH distribution for all the acid-sensitive lakes inhabited by the species (pH rounded to one decimal place). The lower end of the distribution was used to estimate the threshold for extirpation for the species. However, interpretation of the data was often difficult. When a distinct threshold was not apparent (e.g. a series of scattered observations occurred along the pH gradient) only an estimated range for the threshold was given. Furthermore, the nature of the pH distribution for a species depends on the pH distribution of the total number of acid-sensitive lakes surveyed (Fig. 3). When the number of lakes sampled at each pH level is not constant, as in our data set, the number of lakes inhabited by a particular species at a particular pH is not just a function of its tolerance of that pH, but is also a function of the number of lakes sampled at that pH.

The population response of each species to acidification was assessed by examining the changes in occurrence of the species in the surveyed lakes across the pH gradient. Occurrence was calculated only for lakes in northwestern Ontario (Long > 87) or south-central Ontario (Long <87) if the distribution of the species was limited to one of these regions. The fraction of sampled lakes inhabited by a species was calculated for

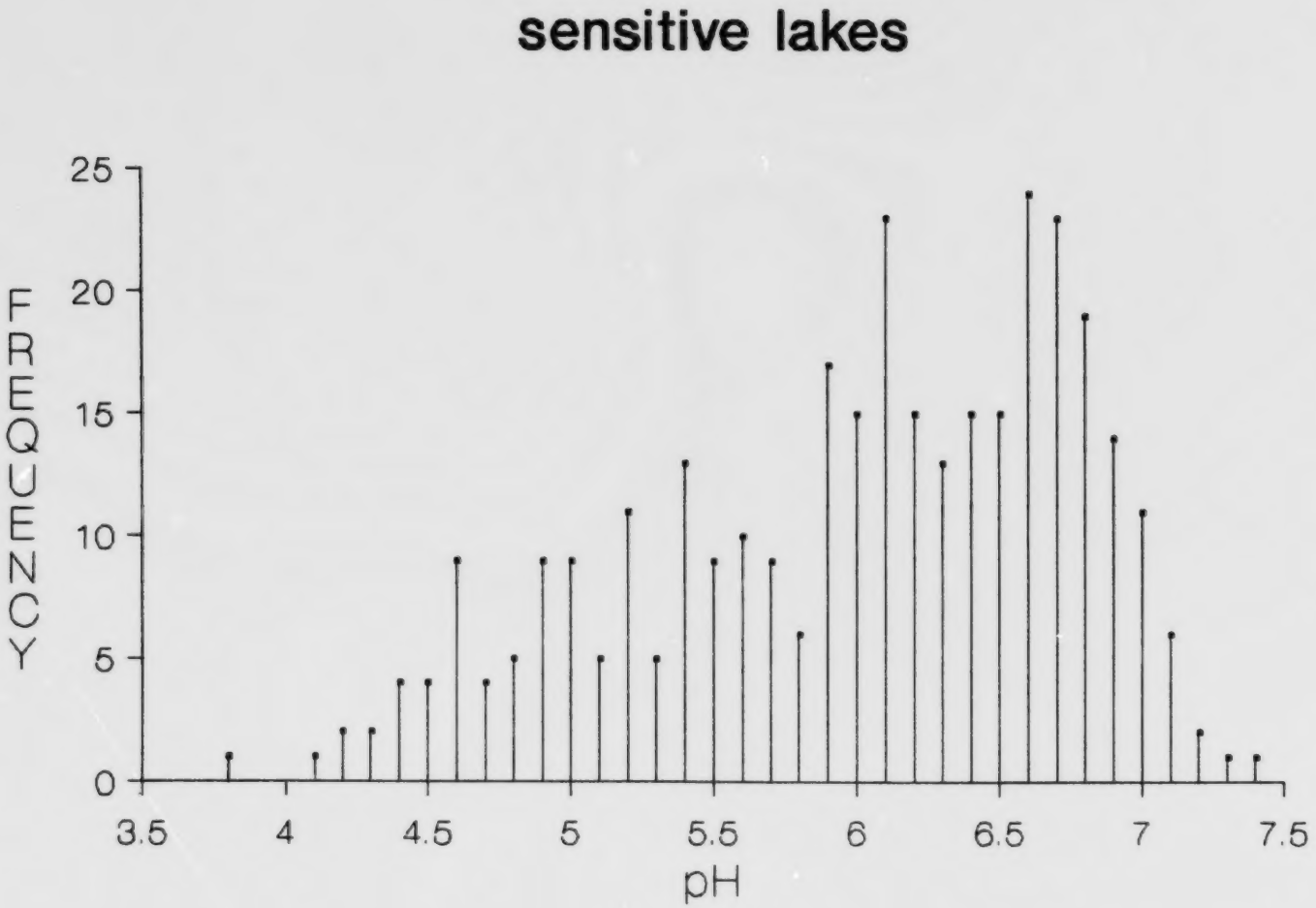


FIGURE 3. pH distribution of surveyed acid-sensitive lakes (alkalinity < 10 mg/l) in Ontario. pH is rounded to one decimal place.

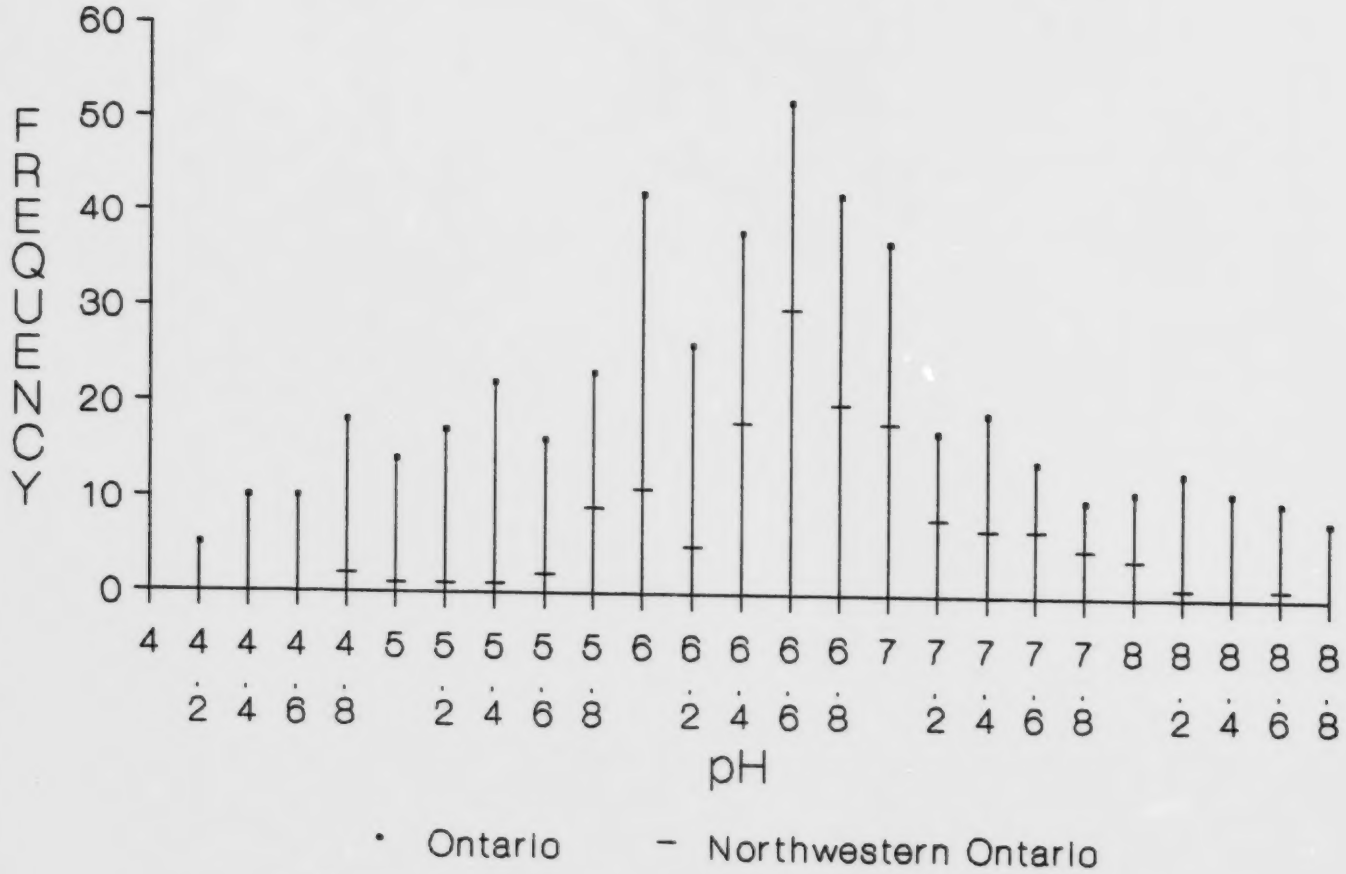


FIGURE 4. Frequency distribution of surveyed lakes in Ontario by pH interval. One pH interval spans 0.2 unit; for example, interval 6.0 includes lakes with $6.0 \leq pH < 6.2$. Intervals with $N \geq 5$ are shown.

each pH interval (0.2 unit) with $\geq$ 5 lakes (Fig. 4). We looked for a large, sudden drop in occurrence at a particular pH, indicating that most populations of the species would exhibit a readily observable decline in size at that pH.

All statistical analyses were performed using the statistical software package SAS (SAS Institute Inc. 1982).

## RESULTS AND DISCUSSION

### TOTAL NUMBER OF SPECIES IN RELATION TO LAKE AREA AND pH

Total number of species increases with lake area in high-pH ($\geq$ 6.0) lakes $\geq$ 10 ha, according to the regression equation: $\log_{10}$ species number = 0.52 + 0.22 * $\log_{10}$ lake area (Fig. 5). This relationship differs from the one reported by Matuszek and Beggs (1988) ($\log_{10}$ species number = 0.41 + 0.20 * $\log_{10}$ lake area), which was developed from a less intensively sampled lake set. The slopes are similar, but the intercept generated from our data set is greater. More species are predicted for a particular lake size with the current equation compared with the one developed earlier. For example, 2.7 more species are predicted in 100 ha lakes, 4.1 species in 500 ha lakes, and 4.9 more species in 1000 ha lakes. Bowlby and Green (1987) estimated that the survey data set used by Matuszek and Beggs (1988) underestimated total species number by an average 4.1 species. Their estimate was based on comparisons with total species numbers in a subset of the lakes used by Matuszek and Beggs (1988) that were resampled in a more intensive manner.

The negative effects of pH on total fish species number, independent of the effects of lake area, are shown in Figure 6. The mean difference between observed number of species and the number predicted by lake area

declines with decreasing pH below pH 6.0. It is more clearly evident in our plot, compared with that of Matuszek and Beggs (1988), that the decline with pH begins abruptly at pH 6.0. Also, the rate of decline is not constant, but decreases with decreasing pH. This contrasts with the gradually increasing rate of decline with decreasing pH that was found by Matuszek and Beggs (1988). These differences are likely due to the more intensive fish sampling done in the current lake set, and the presence of a number of large, highly acidified lakes in the lake set used by Matuszek and Beggs (1988).

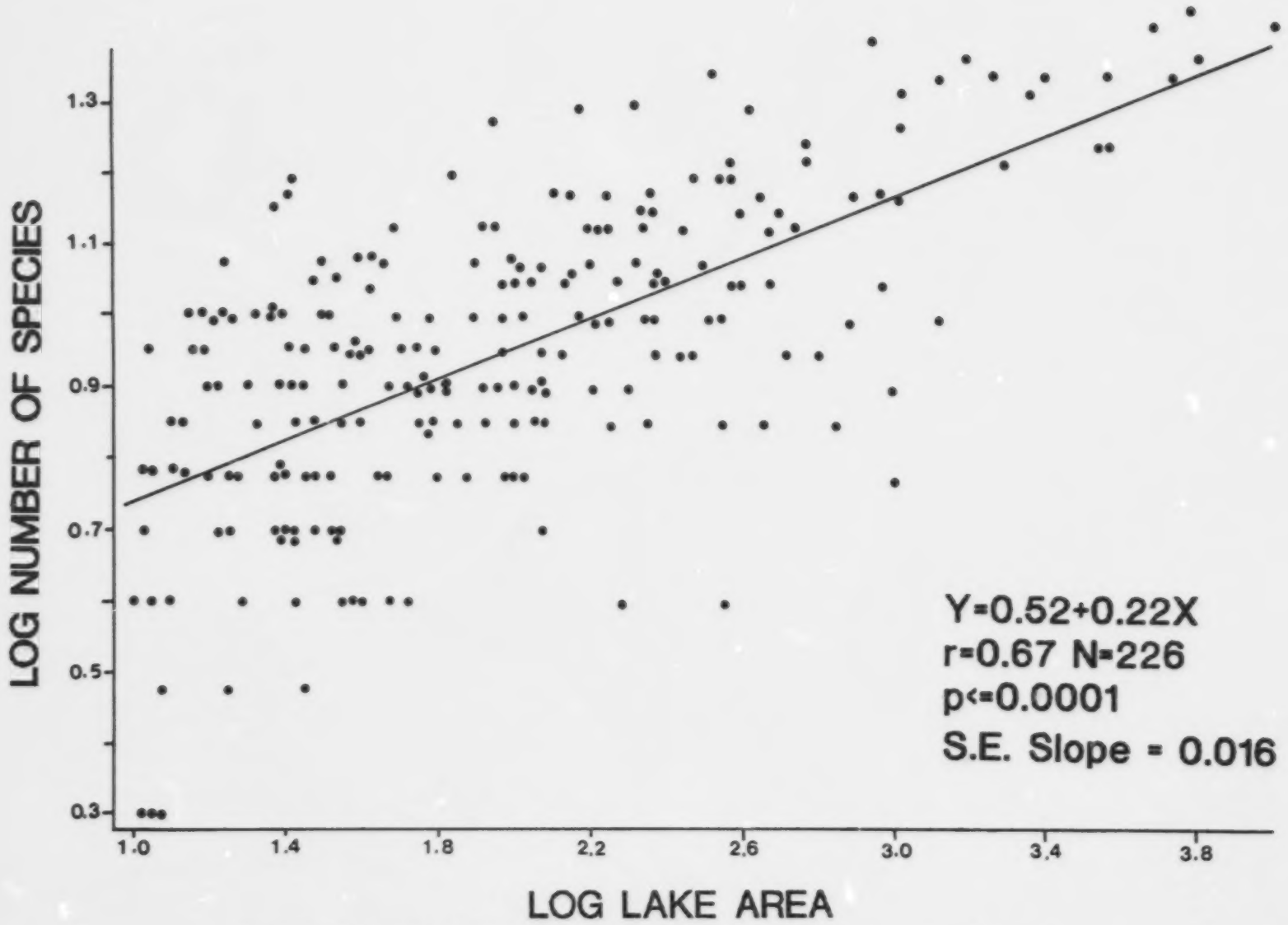


FIGURE 5. Relationship between $\log_{10}$ number of species and $\log_{10}$ lake area for lakes with pH $\geq$ 6.0 and lake area $\geq$ 10 ha.

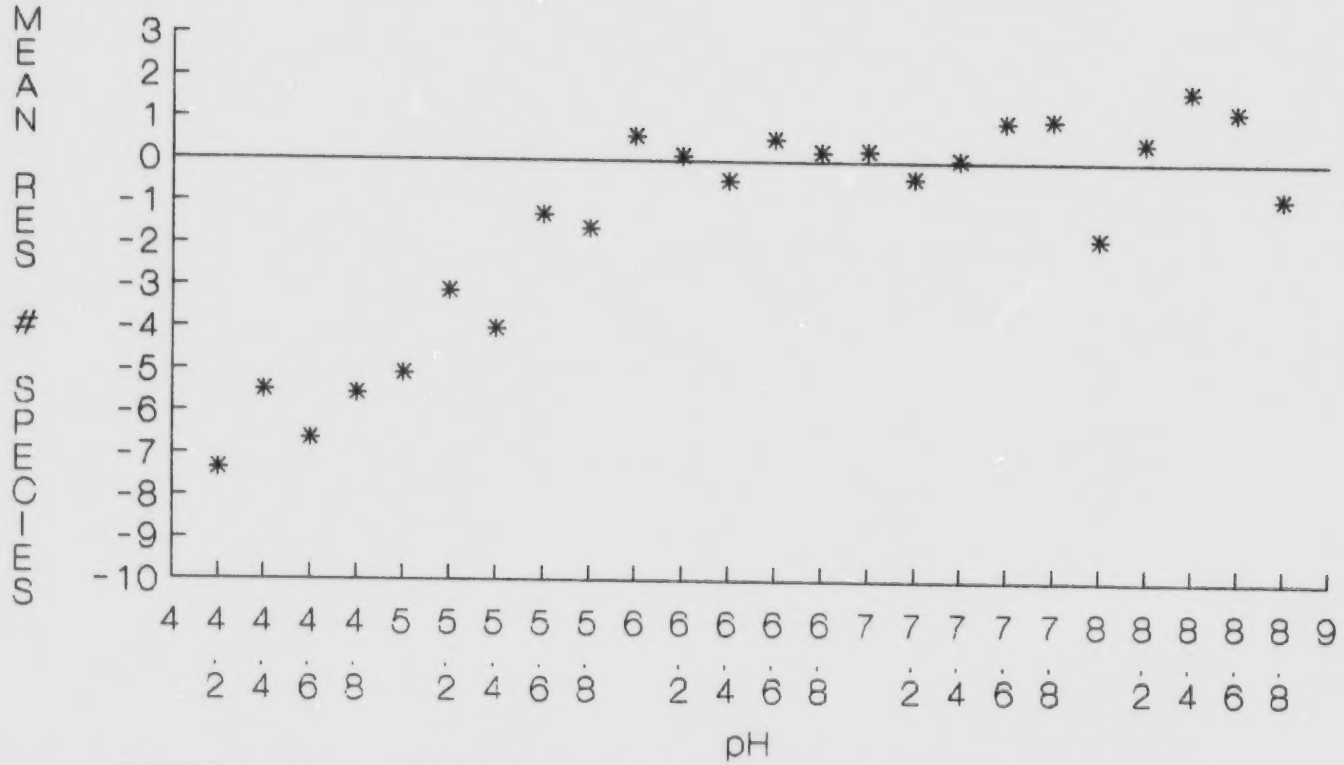


FIGURE 6. Mean residual number of species by pH interval. The residual number of species for a lake is the deviation of the observed number from the number predicted by lake area. One pH interval spans 0.2 unit. The number of lakes per interval, starting at pH 4.2, is: 5, 10, 10, 18, 13 (pH 5.0), 14, 19, 16, 19, 35 (pH 6.0), 20, 27, 39, 32, 24 (pH 7.0), 12, 17, 11, 9, 9 (pH 8.0), 12, 11, 9, and 8.

## NUMBER OF CYPRINID SPECIES IN RELATION TO LAKE AREA AND pH

The plot of mean number of cyprinid species by $\log_{10}$ lake area interval for high-pH ($\geq$ 6.0) lakes indicates little or no effect of lake area over the range 0.8 to 3.0 (Fig. 7). A regression of $\log_{10}$ {cyprinid number of species + 1} on $\log_{10}$ lake area ($0.8 \leq \log_{10}$ lake area $\leq 3.0$) did not produce a slope significantly different from zero ($P = 0.32$). If we consider lake area to be an index of habitat diversity, it is perhaps understandable that the number of cyprinid species does not increase with lake area in the same way as total species number. Cyprinid habitat consists largely of the shallower nearshore regions of lakes and may not be as influenced by differences in lake surface area.

Below the $\log_{10}$ lake area value of 0.8 (6.3 ha), the mean number of cyprinid species drops and stays at a low level of approximately 2 species (Fig. 7). These very small lakes are mainly located in the northwest region of the province (Experimental Lakes Area) where climatic and geographic factors may adversely effect the number of cyprinid species.

In the absence of any distinct relationship between the number of cyprinid species and lake area in our data set, mean number of cyprinid species was plotted against

pH interval without any adjustment for lake area (Fig. 8). Similar to total species number, the mean number of cyprinid species decreases with decreasing pH below pH 6.0. No cyprinid species were found below pH 4.7.

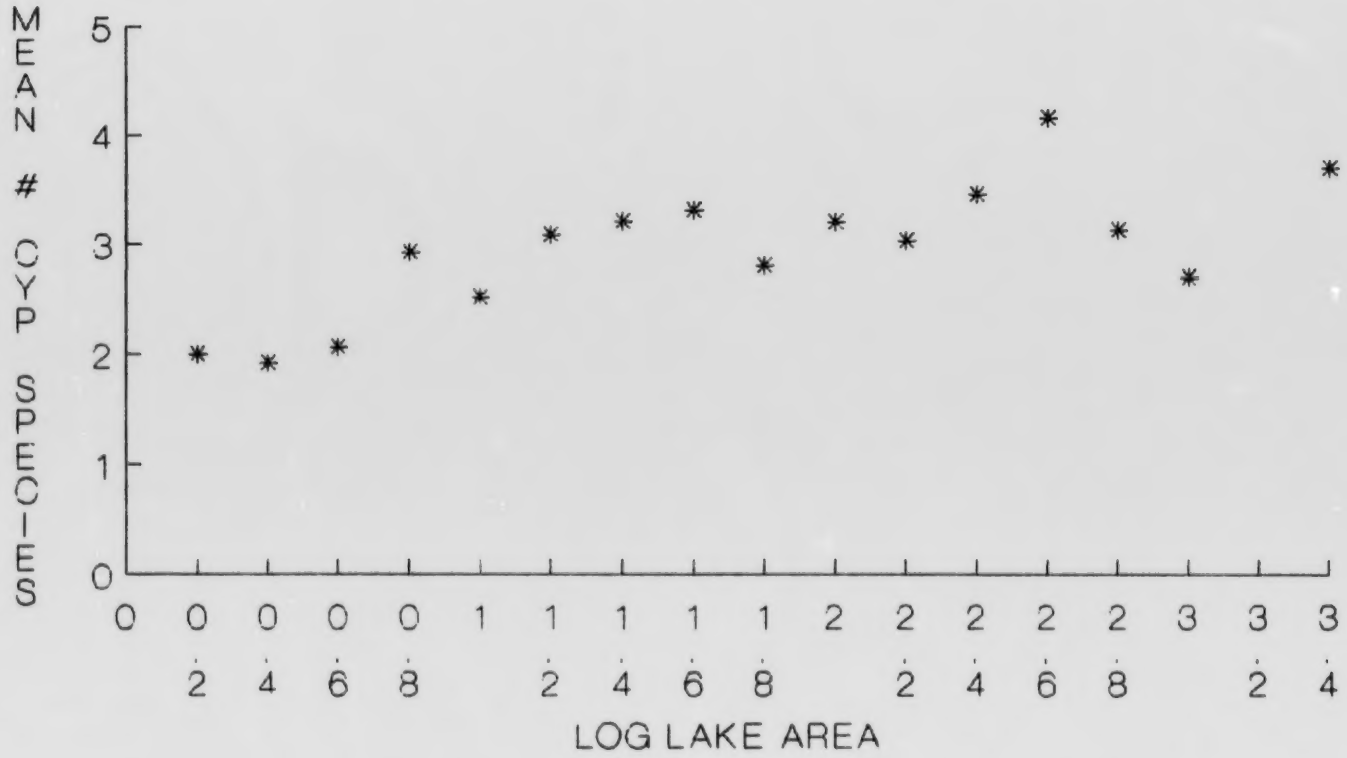


FIGURE 7. Mean number of cyprinid species by lake area interval for lakes with pH $\geq$ 6.0. One lake area interval spans 0.2 unit on the logarithmic scale. The number of lakes per interval, starting at 0.2, is: 8, 12, 28, 37, 27 (1.0), 33, 39, 25, 21, 24 (2.0), 25, 15, 12, 7, 7 (3.0), and 7 (3.4).

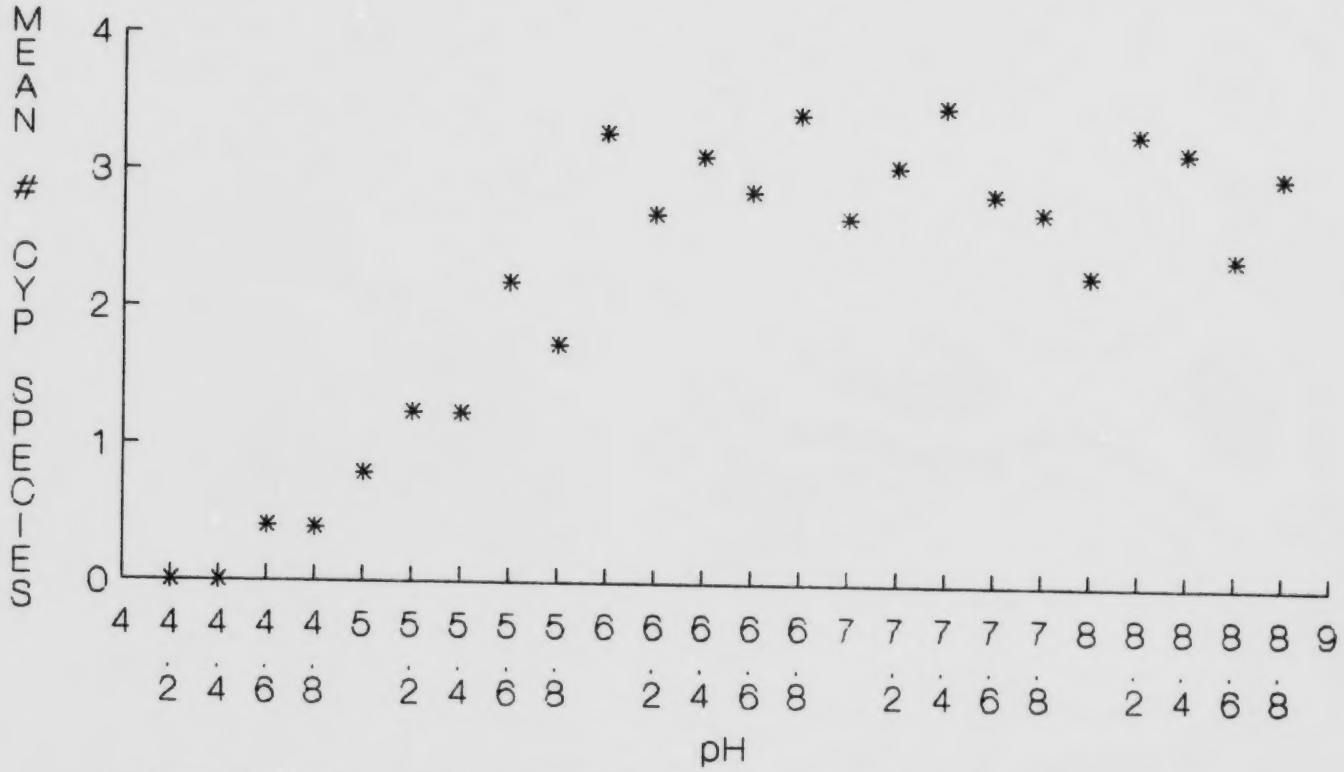


FIGURE 8. Mean number of cyprinid species by pH interval. One pH interval spans 0.2 unit. The number of lakes per interval, starting at 4.2, is: 5, 10, 10, 18, 14 (pH 5.0), 17, 22, 16, 23, 42 (pH 6.0), 27, 38, 52, 43, 38 (pH 7.0), 17, 20, 14, 11, 11 (pH 8.0), 13, 11, 10, and 8.

## CYPRINID FRACTION IN RELATION TO LAKE AREA AND pH

In high-pH ($\geq$ 6.0) lakes the ratio of cyprinid species number to total species number (cyprinid fraction) generally increases with decreasing lake size (Fig. 9). This follows from the previous observations that total species number decreases in smaller lakes, whereas the number of cyprinid species remains constant. The linearity of the relationship between mean cyprinid fraction and lake area was improved by taking the inverse of the mean cyprinid fraction (Fig. 10). The fitted regression equation (1/cyprinid fraction = 0.51 + 1.39 * $\log_{10}$ lake area) was then used to predict the expected cyprinid fraction for each lake based on lake area alone.

The discrepancy between the observed cyprinid fraction and that predicted by lake area decreases with decreasing pH below pH 6.0 (Fig. 11), indicating that a smaller proportion of the cyprinid species found in Ontario lakes is able to tolerate progressively lower pH values compared with other fish species found in these lakes. This supports the thesis that the cyprinid family of fish is particularly sensitive to acidic conditions compared with other groups of fish (Eilers et al. 1984).

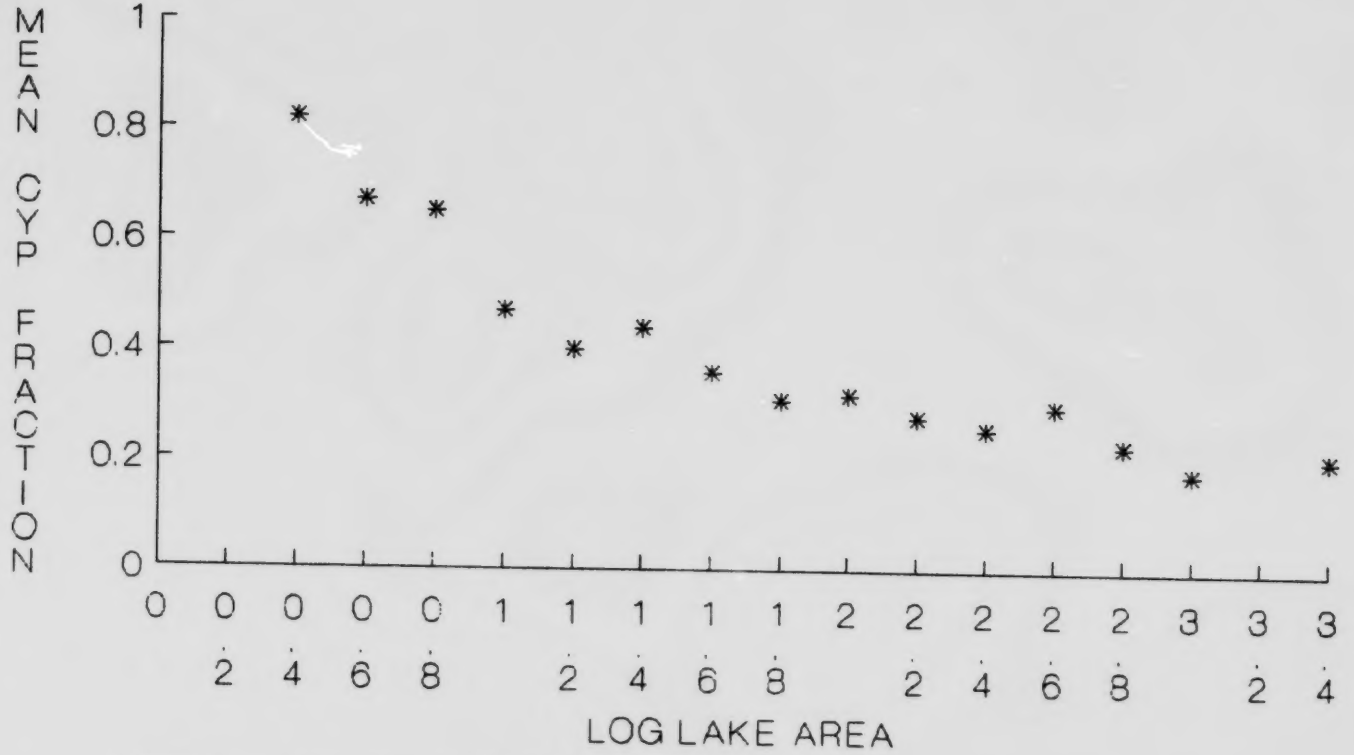


FIGURE 9. Mean cyprinid fraction by lake area interval for lakes with pH $\geq$ 6.0. One lake area interval spans 0.2 unit on the logarithmic scale. The number of lakes per interval, starting at 0.4, is: 5, 16, 22, 21 (1.0), 25, 34, 24, 21, 24 (2.0), 25, 15, 12, 7, 7 (3.0), and 7 (3.4).

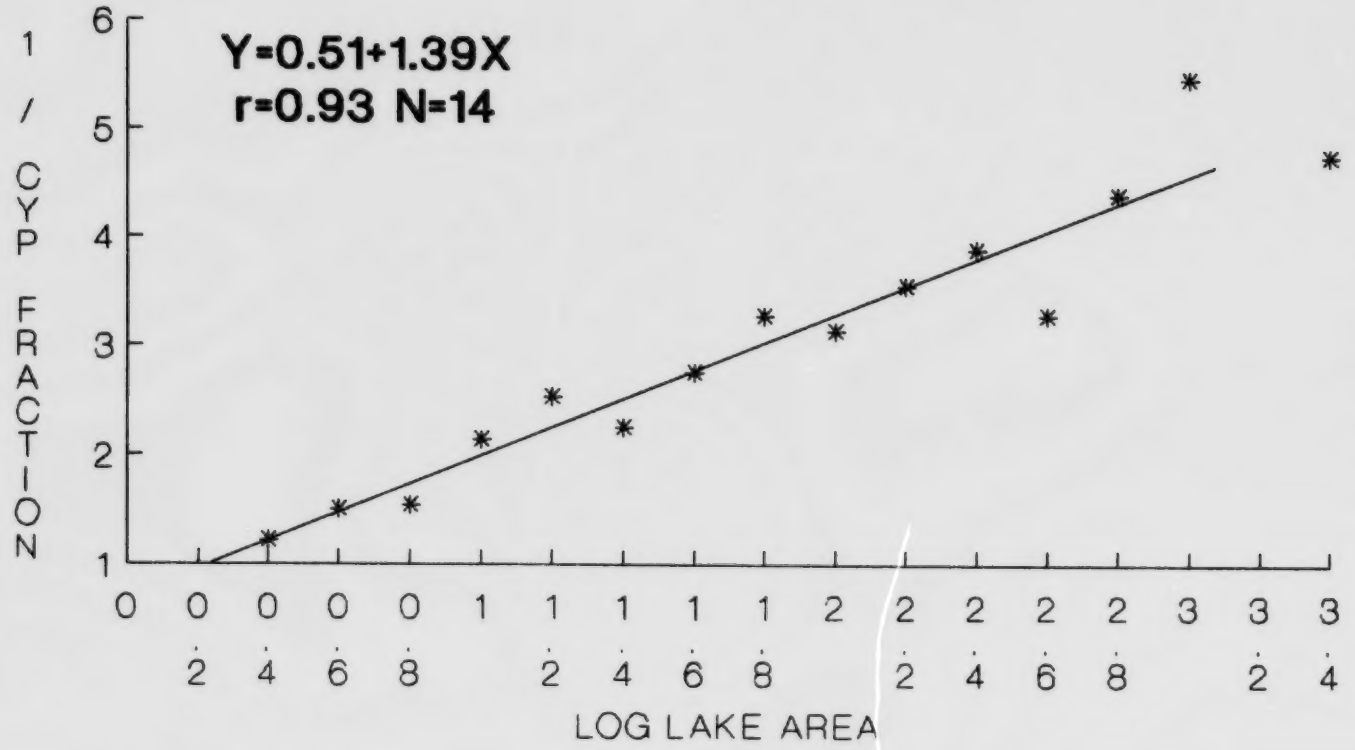


FIGURE 10. Relationship between inverse mean cyprinid fraction and $\log_{10}$ lake area for lakes with pH $\geq$ 6.0. The number of lakes per lake area interval is given in Figure 9.

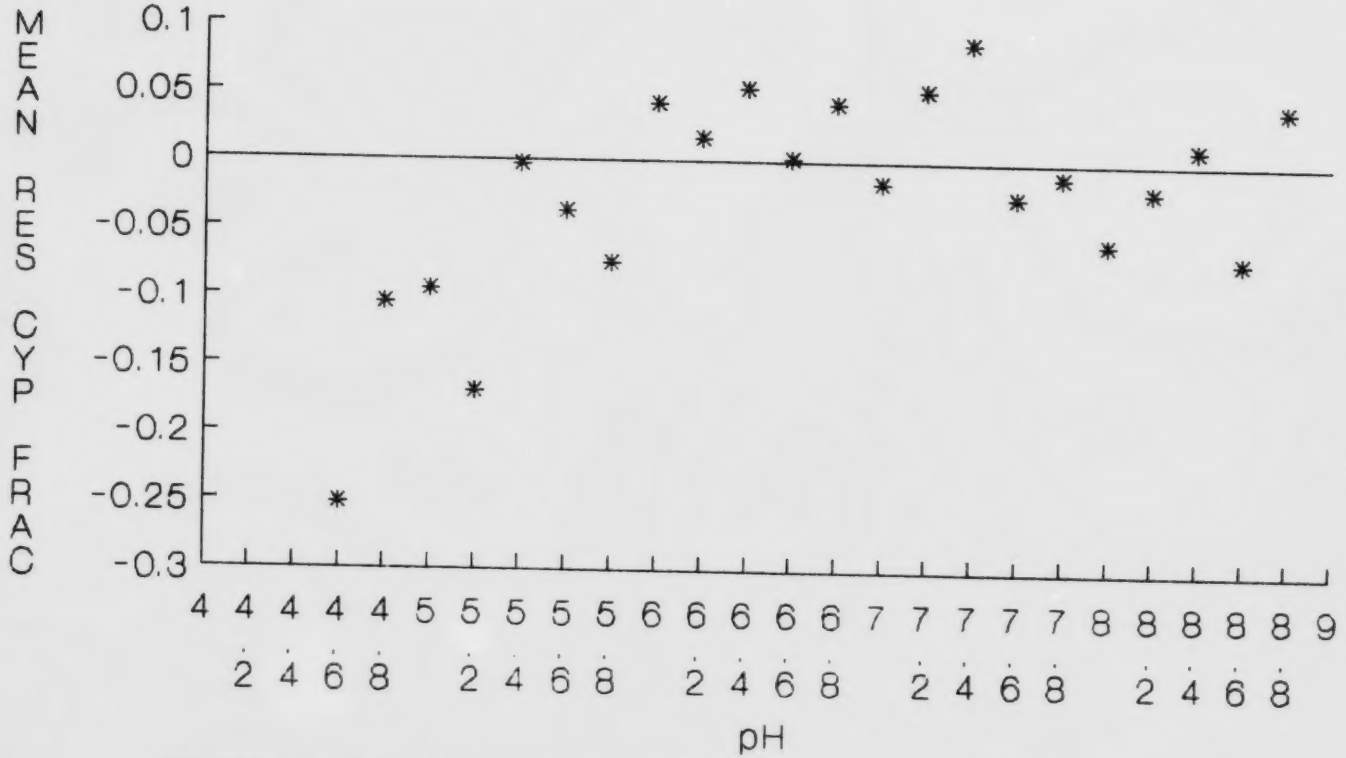


FIGURE 11. Mean residual cyprinid fraction by pH interval. The residual fraction for a lake is the deviation of the observed fraction from the fraction predicted by lake area. One pH interval spans 0.2 unit. The number of lakes per interval, starting at pH 4.6, is: 7, 13, 12 (pH 5.0), 12, 19, 15, 18, 34 (pH 6.0), 20, 25, 39, 32, 25 (pH 7.0), 12, 18, 11, 10, 9 (pH 8.0), 12, 11, 9, and 8.

## SPECIES OCCURRENCE IN ACID-SENSITIVE LAKES

The 30 most common fish species that were found in the acid-sensitive lakes (alkalinity < 10 mg/l) that were sampled intensively for both large and small species (N = 249) are listed in Table 2. About half (53%) of these are small fish species, including 12 cyprinids, 2 darters, 1 stickleback, and 1 sculpin. Because useful indicators of acidification should be relatively common in lakes that are sensitive to acid loading, we examined the 13 small species that were found in at least 10% of the acid-sensitive lakes in our data set.

**Table 2. Species occurrence in acid-sensitive lakes that were sampled for both large and small fish species. The 30 most common species are listed in descending order of occurrence, with the number of lakes in which each species was found, and the fraction of non-barren lakes that contained the species.**

| Common Name | Scientific Name | Number of Lakes | Fraction |
|---|---|---|---|
| White Sucker | Catostomus commersoni | 151 | 0.61 |
| Yellow Perch | Perca flavescens | 133 | 0.53 |
| Pearl Dace | Semotilus margarita | 109 | 0.44 |
| Lake Trout | Salvelinus namaycush | 89 | 0.36 |
| Pumpkinseed | Lepomis gibbosus | 79 | 0.32 |
| Northern Redbelly Dace | Chrosomus eos | 67 | 0.27 |
| Brook Trout | Salvelinus fontinalis | 65 | 0.26 |
| Fathead Minnow | Pimephales promelas | 59 | 0.24 |
| Creek Chub | Semotilus atromaculatus | 59 | 0.24 |
| Brown Bullhead | Ictalurus nebulosus | 57 | 0.23 |
| Brook Stickleback | Culaea inconstans | 53 | 0.21 |
| Golden Shiner | Notemigonus crysoleucas | 52 | 0.21 |
| Iowa Darter | Etheostoma exile | 51 | 0.21 |
| Finescale Dace | Chrosomus neogaeus | 47 | 0.19 |
| Smallmouth Bass | Micropterus dolomieui | 45 | 0.18 |
| Northern Pike | Esox lucius | 44 | 0.18 |
| Common Shiner | Notropis cornutus | 42 | 0.17 |
| Lake Chub | Couesius plumbeus | 41 | 0.17 |
| Bluntnose Minnow | Pimephales notatus | 40 | 0.16 |
| Rock Bass | Ambloplites rupestris | 40 | 0.16 |
| Blacknose Shiner | Notropis heterolepis | 38 | 0.15 |
| Cisco | Coregonus artedii | 35 | 0.14 |
| Burbot | Lota lota | 35 | 0.14 |
| Lake Whitefish | Coregonus clupeaformis | 27 | 0.11 |
| Slimy Sculpin | Cottus cognatus | 27 | 0.11 |
| Longnose Sucker | Catostomus catostomus | 23 | 0.09 |
| Spottail Shiner | Notropis hudsonius | 19 | 0.08 |
| Johnny Darter | Etheostoma nigrum | 18 | 0.07 |
| Longnose Dace | Rhinichthys cataractae | 17 | 0.07 |
| Largemouth Bass | Micropterus salmoides | 14 | 0.06 |

PEARL DACE

The pearl dace was found in acid-sensitive lakes in both northwestern and south-central Ontario (Fig. 12). However, there was a significantly higher rate of occurrence in the northern latitudes (Table 3). Lakes in which the species was present were significantly smaller and at higher elevations than lakes in which it was absent (Table 3). Lakes inhabited by pearl dace exhibited significantly higher levels of pH, alkalinity, and dissolved organic carbon, and lower levels of calcium and aluminum compared with lakes in which it was absent (Table 3). The species appears quite tolerant of low pH, with 20% of inhabited acid-sensitive lakes at pH < 6.0 and a pH threshold for extirpation in the range 4.7 - 5.2 (Fig. 13).

The occurrence of pearl dace in our surveyed lakes generally declines with pH from 66% at pH 6.4 to 32% at pH 5.4 and then drops to an average 11% for pH 4.6 - 5.2 (Fig. 14). The gradual decline in occurrence below pH 6.4 may be more a reflection of uneven sampling and species distributional patterns in Ontario than pH effects. The proportion of surveyed lakes that are located in northwestern Ontario, where the pearl dace is very common, decreases below pH 6.4 (Fig. 4). Furthermore, Mills et al. (1987) found that pearl dace flourished in their experimentally acidified Lake 223 as

pH declined below pH 6.0. Their experiment indicated a pH threshold for recruitment failure of 5.1. However, they argued that their acidification schedule may have produced an estimate that was too low. The drop in the occurrence of pearl dace below pH 5.4 in our survey lakes is most likely a reflection of adverse pH effects and can serve as a rough estimate of the pH threshold for healthy, viable populations. Fish were found in a few lakes with pH < 5.4, but these may represent highly stressed populations and/or exceptional environmental circumstances, such as lakes with sufficient spatial variability in their water chemistry to provide refugia for spawning.

Although the pearl dace may be one of the most common cyprinids in Ontario lakes, the species is relatively tolerant of low pH and therefore not useful as an early indicator of changes in the fish community due to acidification in the usual sense. However, as Mills et al. (1987) have found, an <u>increase</u> in population size may be an early indicator of adverse acidification effects on other members of the community.

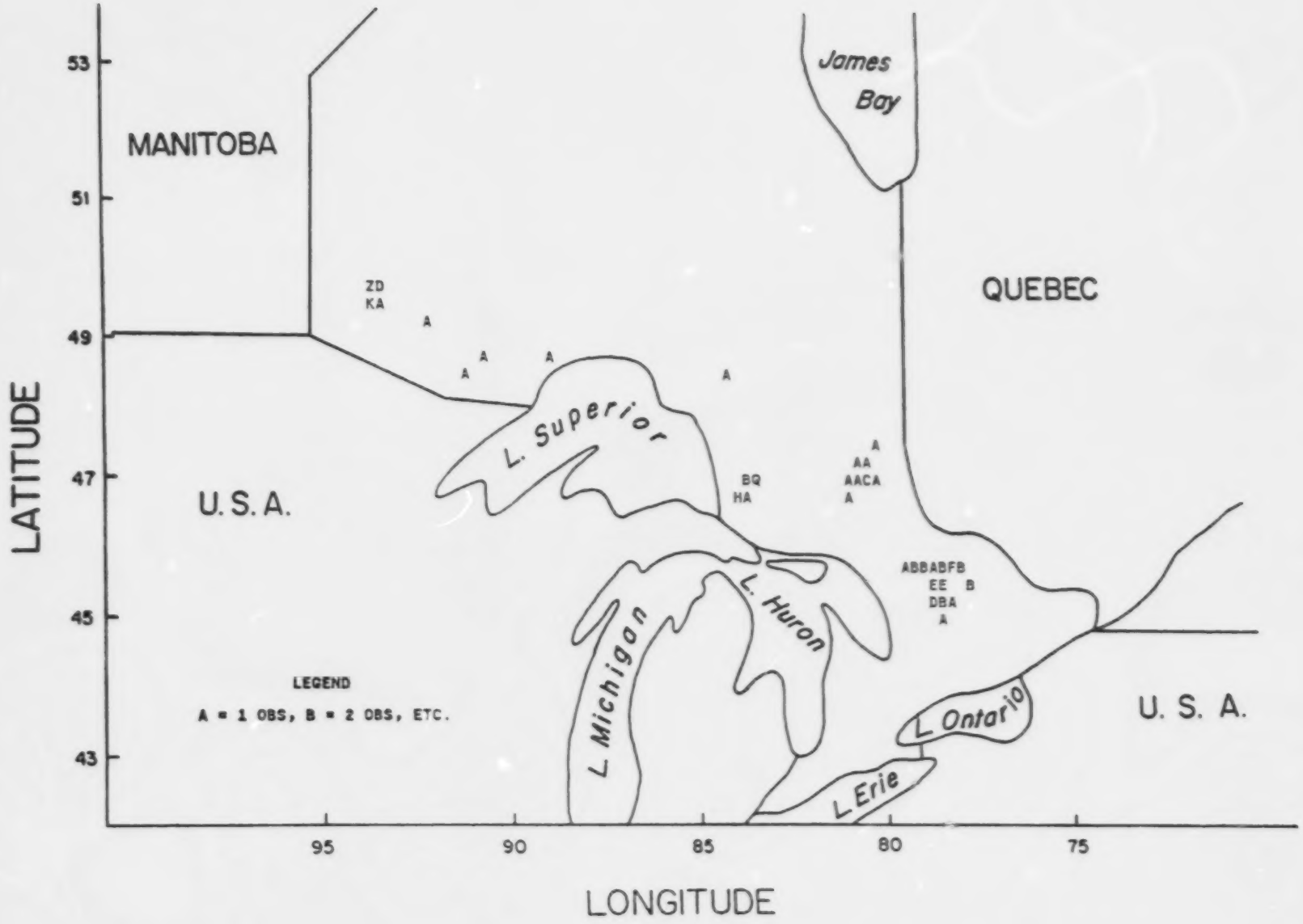


FIGURE 12. Location of acid-sensitive lakes in which the pearl dace was found.

Table 3. Differences between the acid-sensitive lakes in which the pearl dace was present and absent. Significance probabilities are given for T-tests and Wilcoxon rank sum tests. Asterisks indicate variables with significant differences at the 5% level.

| | PRESENT | | | | ABSENT | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Variable | Mean | Median | Range | N | Mean | Median | Range | N | T-Test | Wilcoxon Rank Sum Test |
| pH* | 6.3 | 6.4 | 4.7 - 7.4 | 135 | 5.8 | 5.9 | 3.8 - 7.3 | 197 | 0.0001 | 0.0000 |
| Log Alkalinity+5* | 0.90 | 0.91 | 0.58 - 1.17 | 127 | 0.86 | 0.84 | 0.37 - 1.17 | 135 | 0.0370 | 0.0351 |
| SQRT Calcium* | 1.54 | 1.52 | 0.47 - 2.25 | 130 | 1.59 | 1.58 | 0.42 - 2.65 | 183 | 0.1580 | 0.0447 |
| Log Aluminum* | 1.57 | 1.58 | 0.00 - 2.59 | 61 | 1.88 | 1.96 | 0.70 - 2.87 | 110 | 0.0001 | 0.0000 |
| Log DOC* | 0.71 | 0.71 | -0.40 - 1.33 | 99 | 0.56 | 0.53 | -0.22 - 1.31 | 95 | 0.0017 | 0.0019 |
| Latitude* | 47.8 | 47.1 | 45.0 - 49.8 | 135 | 46.9 | 46.7 | 44.7 - 49.7 | 197 | 0.0001 | 0.0001 |
| Log Lake Area* | 1.43 | 1.29 | 0.28 - 3.81 | 133 | 1.53 | 1.56 | -0.05 - 3.06 | 189 | 0.2149 | 0.0469 |
| SQRT Max Depth | 4.15 | 3.95 | 1.00 - 9.35 | 74 | 4.44 | 4.45 | 1.22 - 8.83 | 149 | 0.3129 | 0.1642 |
| SQRT Mean Depth | 2.97 | 2.71 | 1.58 - 5.22 | 48 | 2.77 | 2.80 | 0.84 - 5.46 | 124 | 0.2034 | 0.4808 |
| Elevation* | 403 | 409 | 312 - 492 | 45 | 324 | 325 | 188 - 534 | 123 | 0.0001 | 0.0000 |
| Log MEI | 0.49 | 0.51 | -0.15 - 1.17 | 43 | 0.59 | 0.54 | -0.22 - 1.47 | 108 | 0.1180 | 0.1925 |
| SQRT (# Species +1)[a] | 2.80 | 2.65 | 1.00 - 5.20 | 82 | 2.78 | 2.82 | 1.00 - 4.69 | 59 | 0.8914 | 0.7501 |

[a]in lakes with pH ≥ 6.0

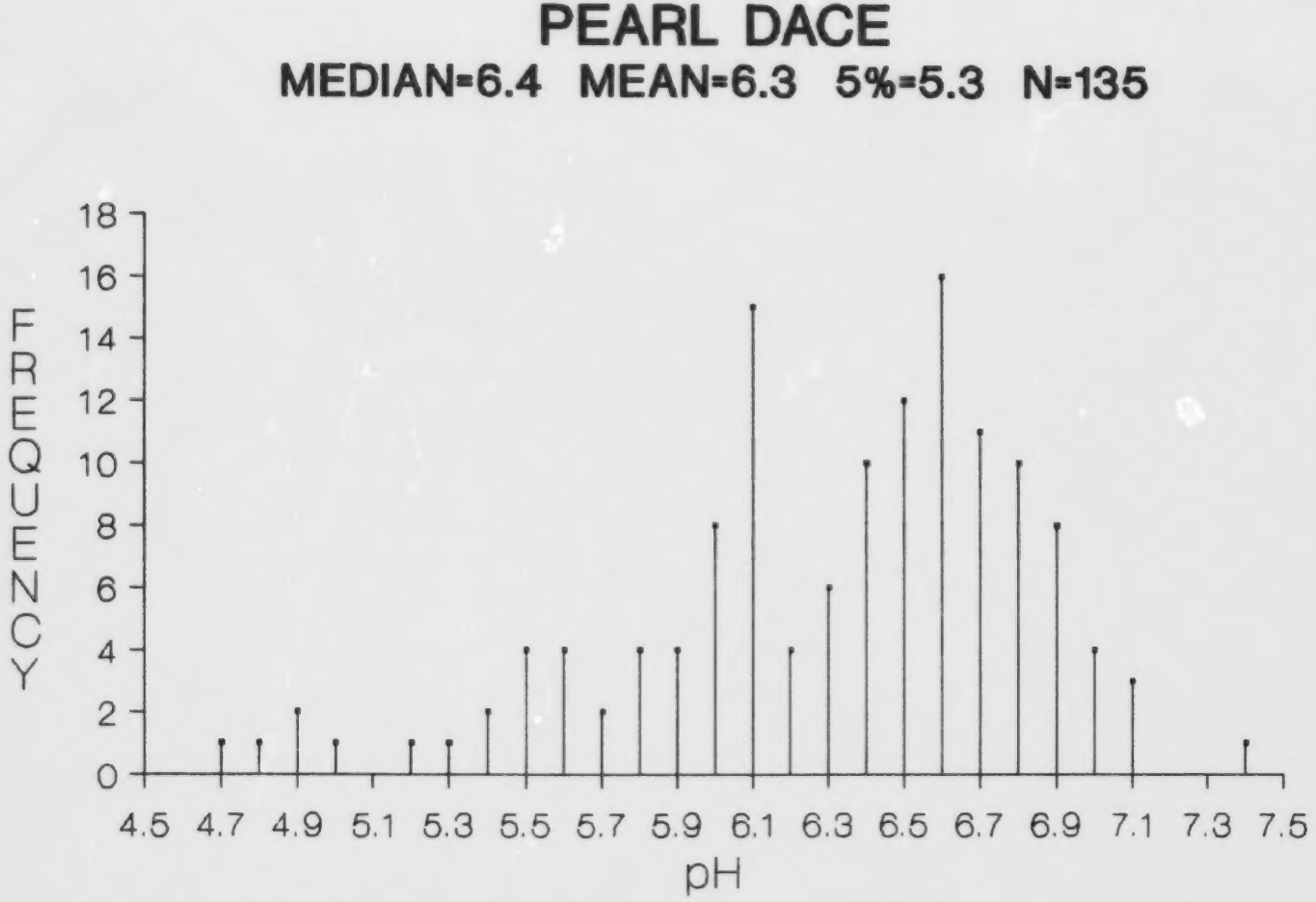


FIGURE 13. pH distribution of acid-sensitive lakes in which the pearl dace was found.

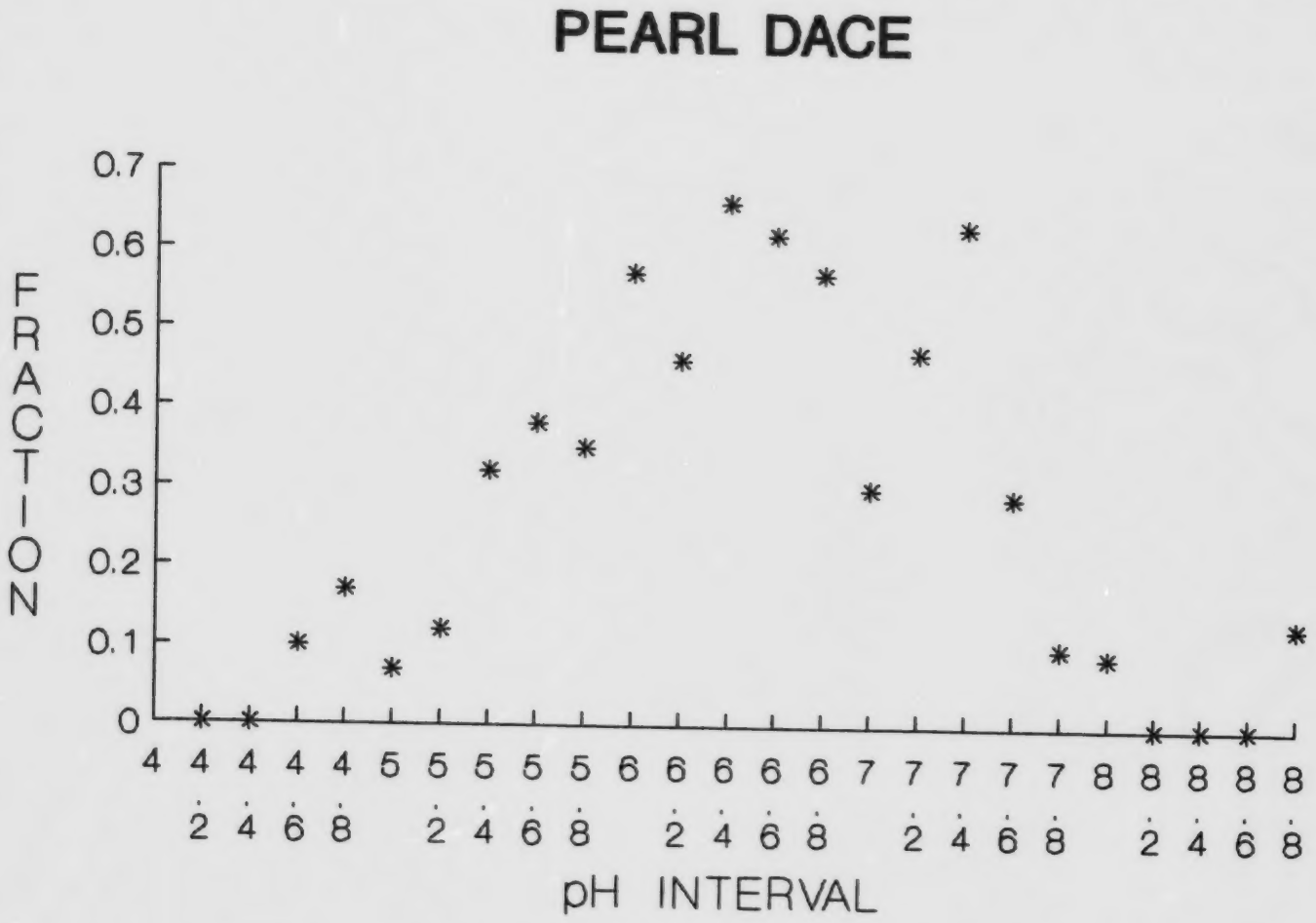


FIGURE 14. Fraction of surveyed lakes in which the pearl dace was found, by pH interval of 0.2 unit.

NORTHERN REDBELLY DACE

The northern redbelly dace was found in acid-sensitive lakes in both northwestern and south-central Ontario (Fig. 15). However, there was a significantly higher rate of occurrence in the southern latitudes (Table 4). Lakes in which the species was present were significantly larger, with greater maximum depths, and were at higher elevations than lakes in which it was absent (Table 4). Inhabited lakes also had significantly lower aluminum concentrations and more fish species than uninhabited lakes (Table 4). The northern redbelly dace is acid- tolerant, with 33% of inhabited acid-sensitive lakes at pH < 6.0 and a pH threshold for extirpation of about 5.0 (Fig. 16). In a set of 138 lakes in Wisconsin, U.S.A., the pH distribution for this species extended to about 5.3 (N = 13) (Rahel and Magnuson 1983).

Species occurrence fluctuates about an average of 25% of our surveyed lakes from pH 5.0 to 7.0 and drops to 0% below pH 5.0 (Fig. 17).

The northern redbelly dace is a common, well distributed species in Ontario, but is acid-tolerant and therefore unsuitable as an early indicator of changes in the fish community due to acidification.

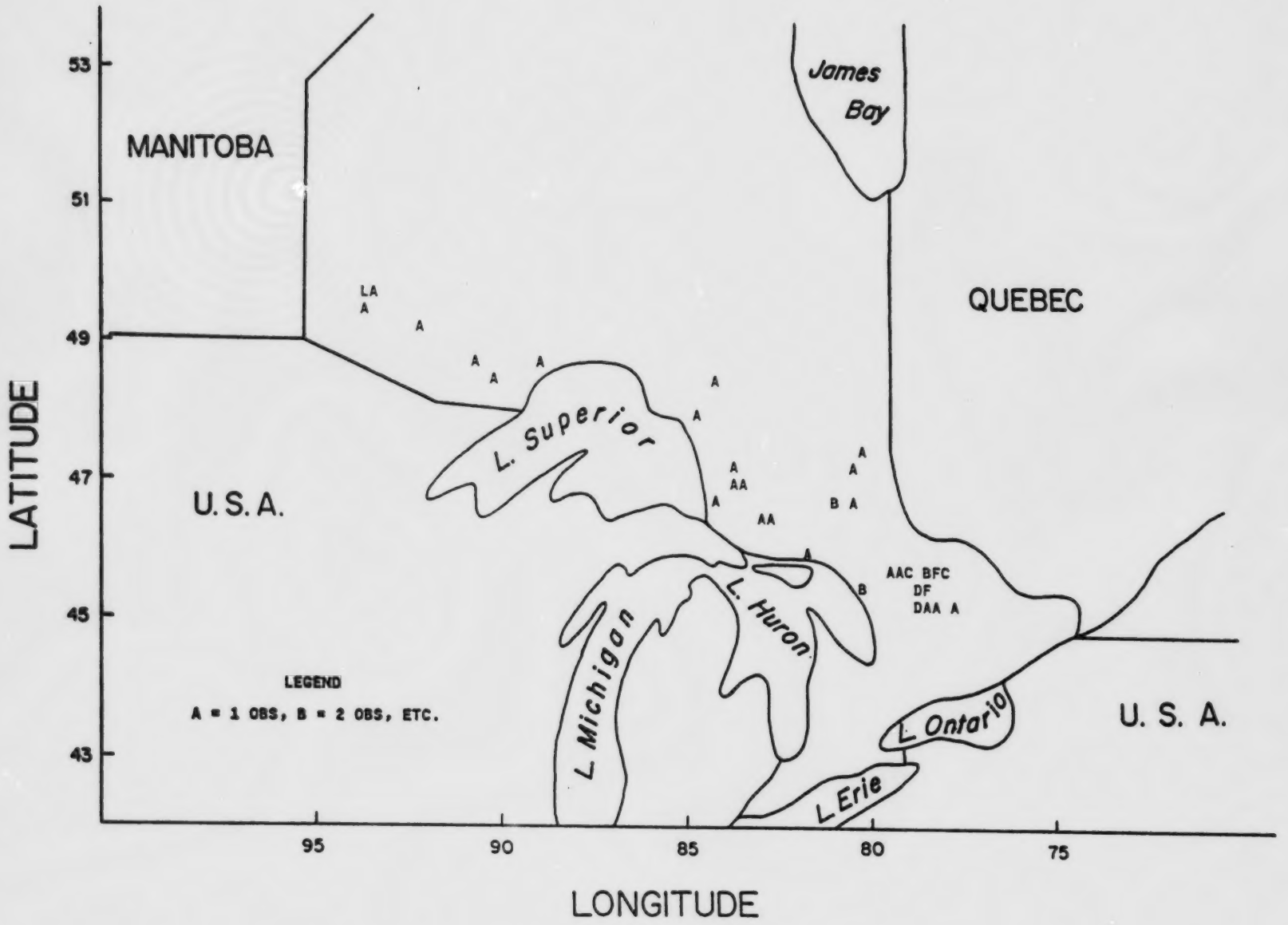


FIGURE 15. Location of acid-sensitive lakes in which the northern redbelly dace was found.

Table 4. Differences between the acid-sensitive lakes in which the northern redbelly dace was present and absent. Significance probabilities are given for T-tests and wilcoxon rank sum tests. Asterisks indicate variables with significant differences at the 5% level.

| | PRESENT | | | | ABSENT | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Variable | Mean | Median | Range | N | Mean | Median | Range | N | T-Test | Wilcoxon Rank Sum Test |
| pH | 6.1 | 6.1 | 5.0 - 7.1 | 67 | 6.0 | 6.1 | 3.8 - 7.4 | 265 | 0.0376 | 0.3148 |
| Log Alkalinity+5 | 0.89 | 0.90 | 0.67 - 1.15 | 58 | 0.88 | 0.89 | 0.37 - 1.17 | 204 | 0.7848 | 0.7653 |
| SQRT Calcium | 1.56 | 1.52 | 0.42 - 2.51 | 62 | 1.57 | 1.55 | 0.44 - 2.65 | 251 | 0.7534 | 0.7509 |
| Log Aluminum* | 1.56 | 1.58 | 0.70 - 2.28 | 45 | 1.84 | 1.92 | 0.00 - 2.87 | 126 | 0.0007 | 0.0004 |
| Log DOC | 0.61 | 0.59 | 0.11 - 1.14 | 59 | 0.65 | 0.70 | -0.40 - 1.33 | 135 | 0.4259 | 0.2902 |
| Latitude* | 46.9 | 45.8 | 45.2 - 49.8 | 67 | 47.3 | 47.1 | 44.7 - 49.7 | 265 | 0.0383 | 0.0015 |
| Log Lake Area* | 1.67 | 1.52 | 0.56 - 3.71 | 64 | 1.45 | 1.39 | -0.05 - 3.81 | 258 | 0.0271 | 0.0380 |
| SQRT Max Depth* | 4.97 | 4.69 | 1.34 - 8.37 | 46 | 4.18 | 4.17 | 1.00 - 9.35 | 177 | 0.0099 | 0.0101 |
| SQRT Mean Depth | 2.81 | 2.71 | 0.84 - 4.83 | 46 | 2.83 | 2.76 | 0.95 - 5.46 | 126 | 0.9050 | 0.8369 |
| Elevation* | 403 | 412 | 213 - 492 | 44 | 325 | 326 | 188 - 534 | 124 | 0.0001 | 0.0000 |
| Log MEI | 0.56 | 0.48 | -0.10 - 1.36 | 44 | 0.56 | 0.54 | -0.22 - 1.47 | 107 | 0.9168 | 0.7916 |
| SQRT (# Species +1)[a]* | 3.05 | 3.00 | 1.41 - 5.20 | 45 | 2.67 | 2.65 | 1.00 - 4.90 | 96 | 0.0167 | 0.0235 |

[a]in lakes with pH ≥ 6.0

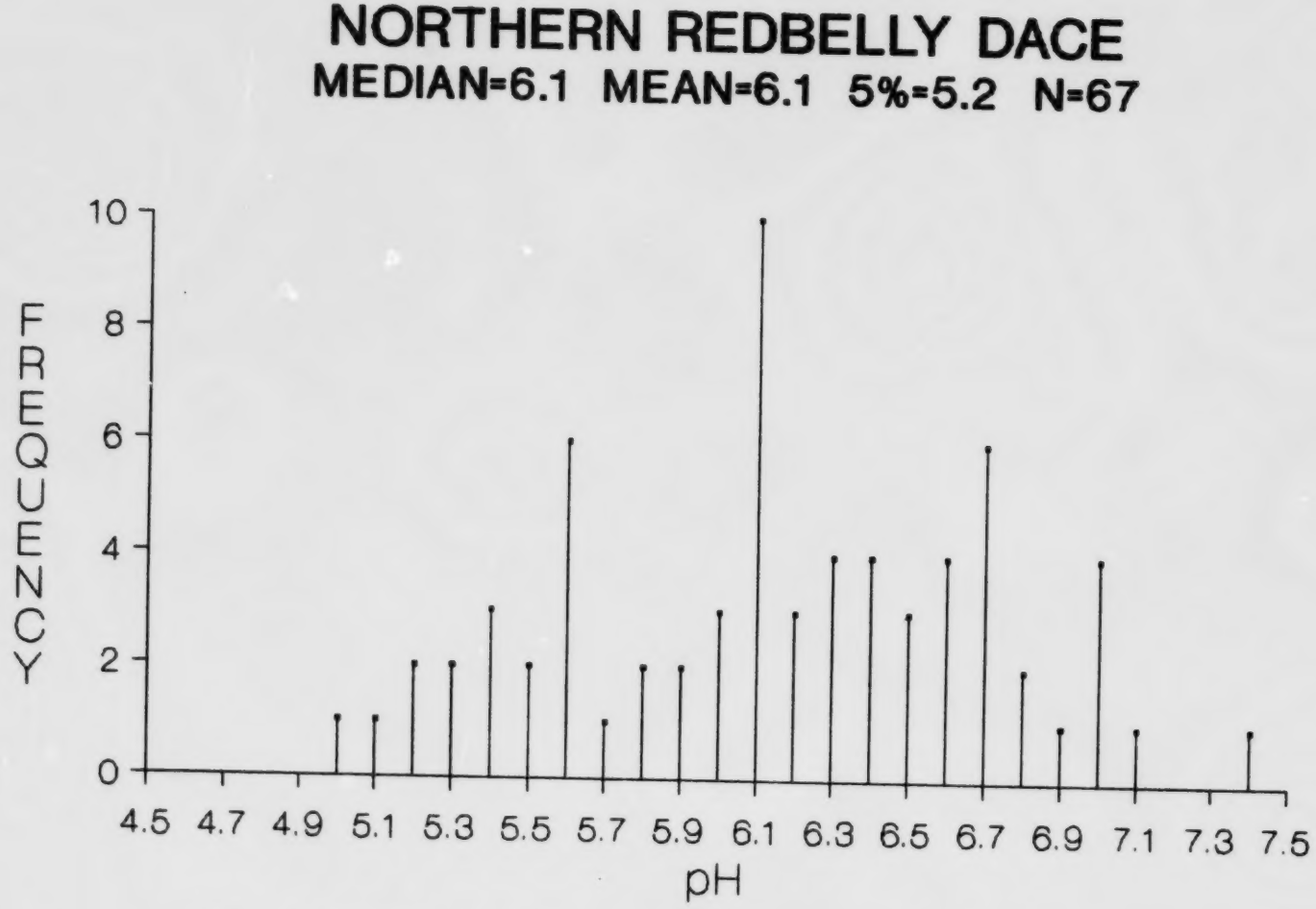


FIGURE 16. pH distribution of acid-sensitive lakes in which the northern redbelly dace was found.

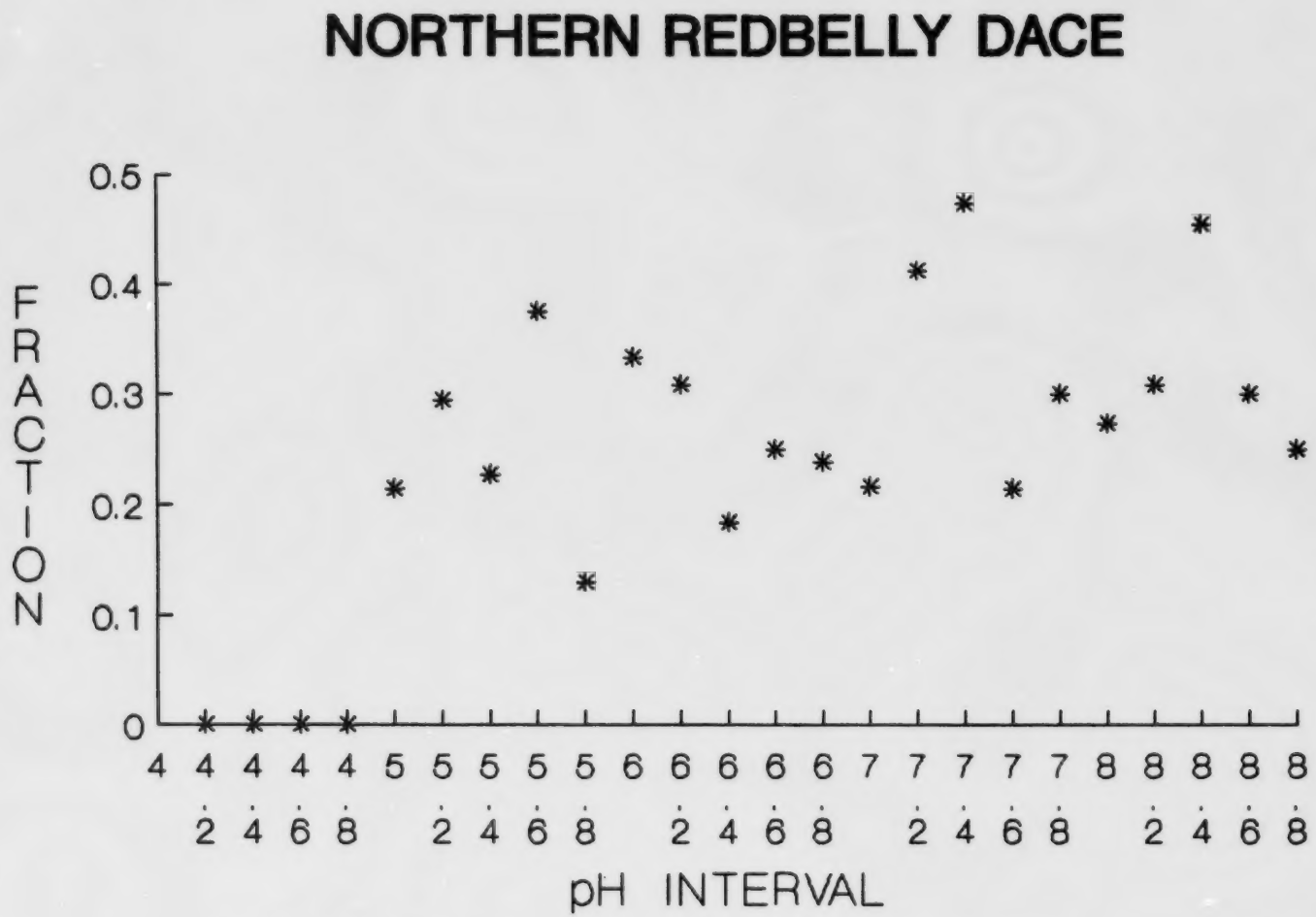


FIGURE 17. Fraction of surveyed lakes in which the northern redbelly dace was found, by pH interval of 0.2 unit.

FATHEAD MINNOW

The fathead minnow was found in acid-sensitive lakes in both northwestern and south-central Ontario (Fig. 18). However, there was a significantly higher rate of occurrence in the northern latitudes (Table 5). Lakes in which the species was present were at significantly higher elevations, and had significantly higher values for pH, alkalinity, and dissolved organic carbon, and lower values for aluminum compared with lakes in which it was absent (Table 5). The fathead minnow is an acid-sensitive species, with only 8% of inhabited acid-sensitive lakes at pH < 6.0 and a pH threshold for extirpation in the range 5.5 - 5.8 (Fig. 19). Mills et al. (1987) estimated the pH threshold for recruitment failure for the fathead minnow as 5.9 in their experimentally acidified Lake 223. Zischke et al. (1983) found that the survival of larval fish decreased at pH 6.0 in experimental outdoor channels. In the laboratory Mount (1973) found that the hatchability of fathead minnow eggs decreased at pH 5.9.

The occurrence of fathead minnow in our survey lakes drops from an average 34% in the pH range 6.0 - 6.6, to an average 9% in the range 5.4 - 5.8, and then to 0% below pH 5.4 (Fig. 20). Adverse population effects associated with pH are indicated at pH < 6.0.

The fathead minnow is a good candidate for consideration as an early indicator of acidification stress on the fish community. It is widely distributed in acid-sensitive lakes in Ontario and is relatively common, occurring in 24% of our surveyed lakes. Occurrence drops dramatically from a high level at pH $\geq$ 6.0 to a very low level below pH 6.0, indicating that there is a high probability that a monitored population will exhibit observable changes due to acidification early in the pH decline. A sudden drop in occurrence to near 0% at an appropriate pH is desirable in an indicator species because there would be little chance that a monitored population would persist at lower pH levels than expected and not exhibit the early warning signs that were desired.

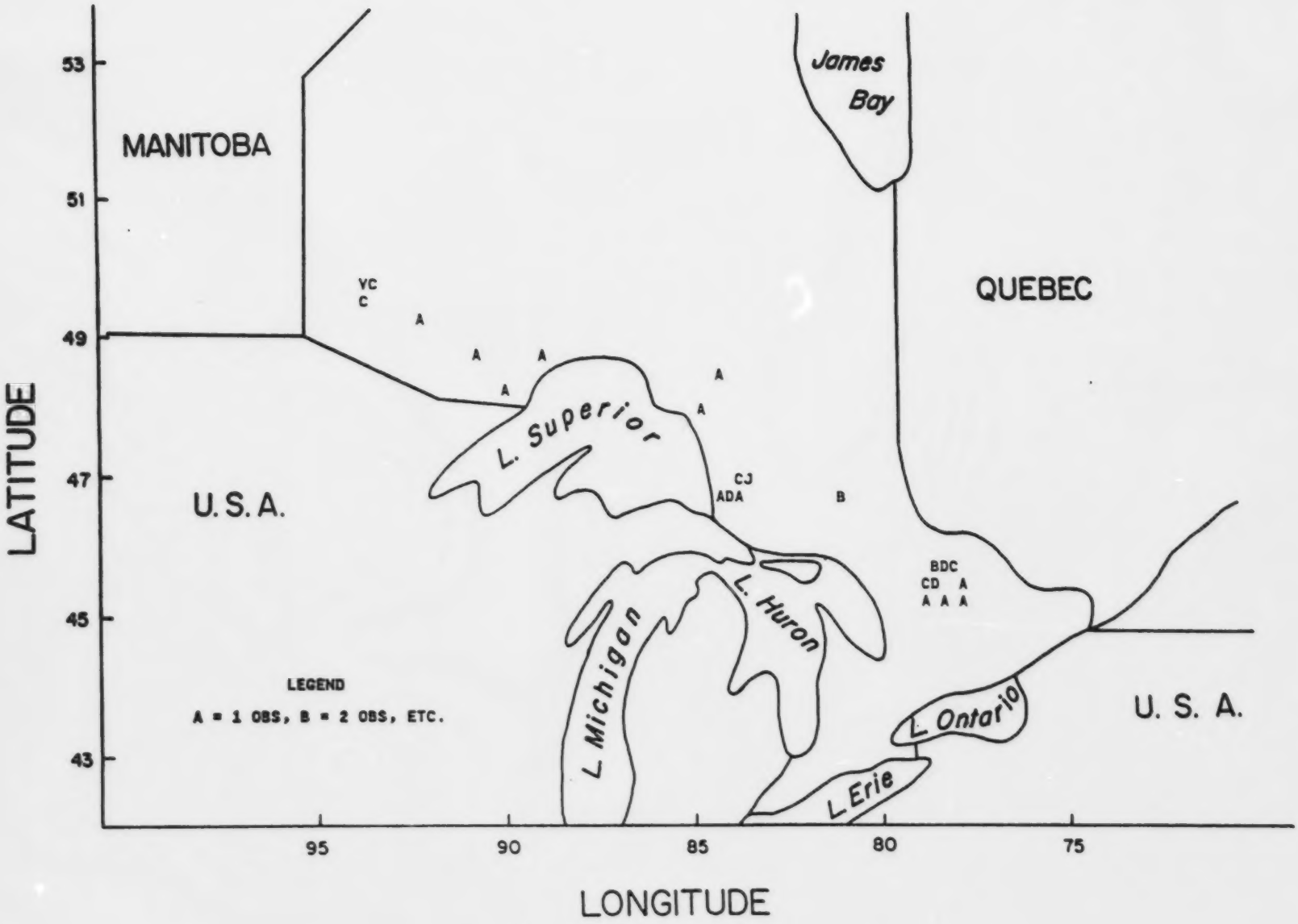


FIGURE 18. Location of acid-sensitive lakes in which the fathead minnow was found.

Table 5. Differences between the acid-sensitive lakes in which the fathead minnow was present and absent. Significance probabilities are given for T-tests and Wilcoxon rank sum tests. Asterisks indicate variables with significant differences at the 5% level.

| | PRESENT | | | | ABSENT | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Variable | Mean | Median | Range | N | Mean | Median | Range | N | T-Test | Wilcoxon Rank Sum Test |
| pH* | 6.5 | 6.5 | 5.5 - 7.3 | 75 | 5.85 | 5.94 | 3.8 - 7.4 | 257 | 0.0001 | 0.0000 |
| Log Alkalinity+5* | 0.95 | 0.95 | 0.72 - 1.16 | 70 | 0.86 | 0.85 | 0.37 - 1.17 | 192 | 0.0001 | 0.0000 |
| SQRT Calcium | 1.62 | 1.58 | 1.00 - 2.51 | 72 | 1.55 | 1.55 | 0.42 - 2.65 | 241 | 0.1614 | 0.2764 |
| Log Aluminum* | 1.48 | 1.53 | 0.00 - 2.28 | 31 | 1.83 | 1.89 | 0.70 - 2.87 | 140 | 0.0001 | 0.0002 |
| Log DOC* | 0.72 | 0.74 | 0.11 - 1.25 | 53 | 0.61 | 0.57 | -0.40 - 1.33 | 141 | 0.0163 | 0.0455 |
| Latitude* | 47.7 | 47.1 | 45.3 - 49.7 | 75 | 47.1 | 46.8 | 44.7 - 49.8 | 257 | 0.0037 | 0.0192 |
| Log Lake Area | 1.40 | 1.29 | 0.28 - 3.71 | 73 | 1.52 | 1.51 | -0.05 - 3.81 | 249 | 0.2216 | 0.0917 |
| SQRT Max Depth | 3.91 | 3.68 | 1.10 - 8.53 | 42 | 4.44 | 4.45 | 1.00 - 9.35 | 181 | 0.0932 | 0.0773 |
| SQRT Mean Depth | 2.86 | 2.59 | 1.58 - 5.22 | 27 | 2.82 | 2.76 | 0.84 - 5.46 | 145 | 0.8623 | 0.8071 |
| Elevation* | 421 | 420 | 335 - 534 | 26 | 331 | 345 | 188 - 503 | 142 | 0.0001 | 0.0000 |
| Log MEI | 0.56 | 0.53 | -0.10 - 1.17 | 26 | 0.56 | 0.52 | -0.22 - 1.47 | 125 | 0.9546 | 0.8130 |
| SQRT (# Species +1)[a] | 2.84 | 2.65 | 1.00 - 5.20 | 53 | 2.76 | 2.83 | 1.00 - 4.90 | 88 | 0.6043 | 0.8560 |

[a]in lakes with pH ≥ 6.0

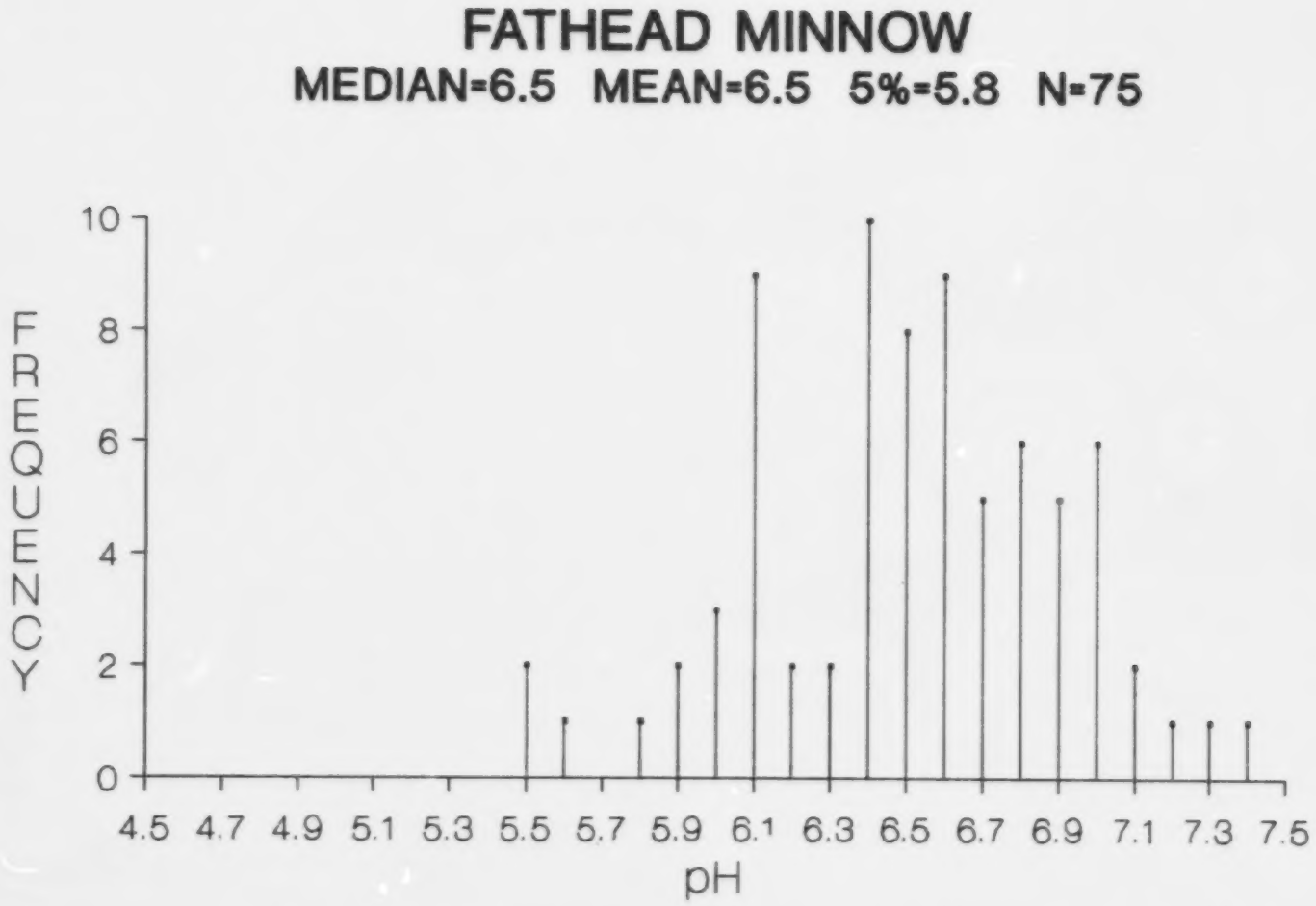


FIGURE 19. pH distribution of acid-sensitive lakes in which the fathead minnow was found.

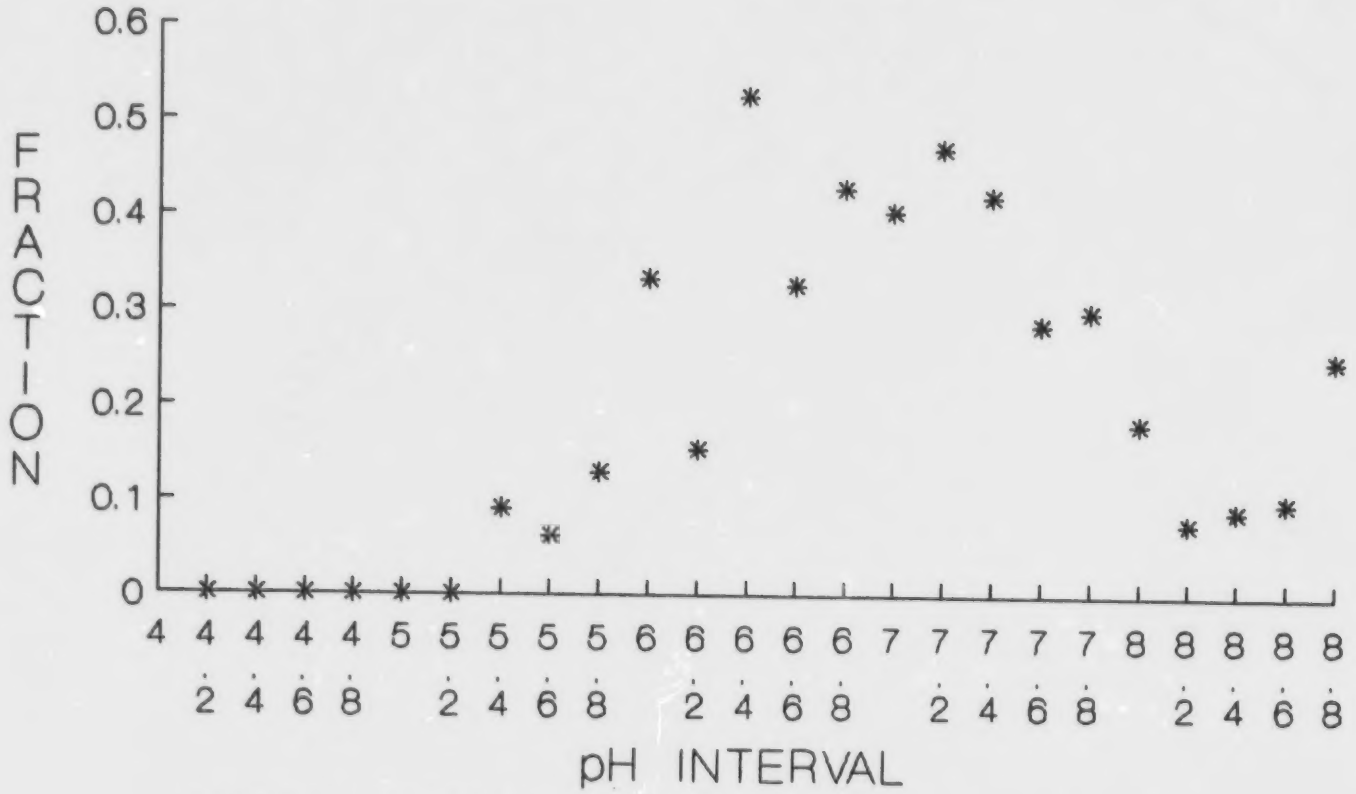


FIGURE 20. Fraction of surveyed lakes in which the fathead minnow was found, by pH interval of 0.2 unit.

CREEK CHUB

The creek chub was found in acid-sensitive lakes only in south-central Ontario (Fig. 21). Lakes in which the species was present were at significantly higher elevations, had significantly higher values for pH, alkalinity, and dissolved organic carbon, lower values for aluminum, and were less productive (lower MEI) than lakes in which it was absent (Table 6). Lakes with creek chub contained more species than lakes without creek chub (Table 6). The species is acid-tolerant, with 21% of inhabited acid-sensitive lakes at pH < 6.0 and a pH threshold for extirpation in the range 5.0 - 5.2 (Fig. 22).

The occurrence of creek chub in our surveyed lakes in south-central Ontario averages 50% for pH 5.6 - 6.8 (Fig. 23). A substantial drop to 19% occurs at pH 5.4, followed by another drop to 0% at pH 5.0 (Fig.23). These changes in occurrence indicate that adverse changes associated with pH will likely occur in many populations at pH < 5.6 and in virtually all populations at pH < 5.2.

Since reliable changes in creek chub populations can only be expected below pH 5.2, the species is unsuitable as an early indicator of changes in the fish community due to acidification.

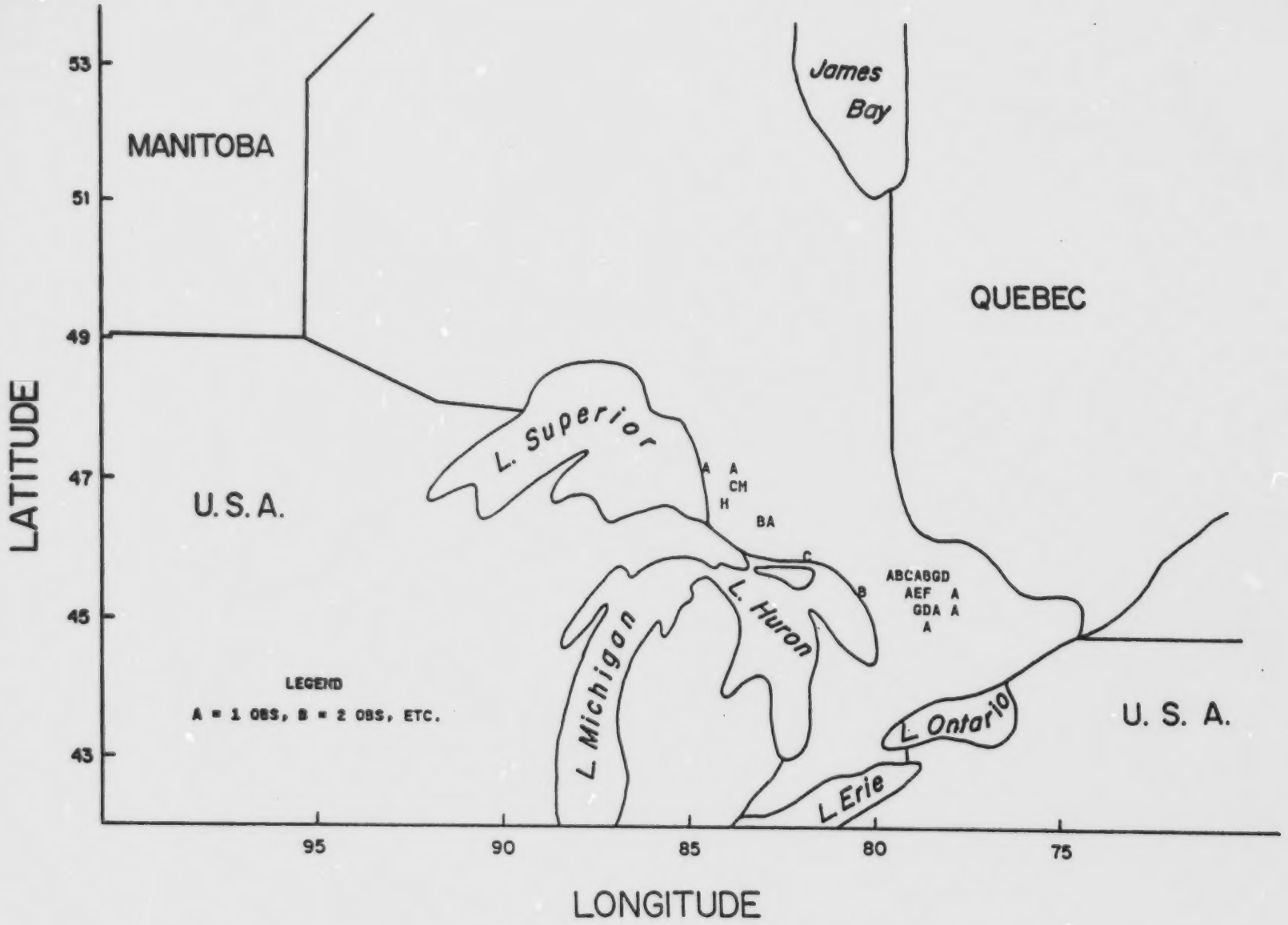


FIGURE 21. Location of acid-sensitive lakes in which the creek chub was found.

Table 6. Differences between the acid-sensitive lakes in south-central Ontario in which the creek chub was present and absent. Significance probabilities are given for T-tests and Wilcoxon rank sum tests. Asterisks indicate variables with significant differences at the 5% level.

| | PRESENT | | | | ABSENT | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Variable | Mean | Median | Range | N | Mean | Median | Range | N | T-Test | Wilcoxon Rank Sum Test |
| pH* | 6.3 | 6.3 | 5.0 - 7.1 | 81 | 5.6 | 5.5 | 3.8 - 7.2 | 157 | 0.0001 | 0.0000 |
| Log Alkalinity+5* | 0.90 | 0.88 | 0.67 - 1.16 | 76 | 0.82 | 0.75 | 0.37 - 1.17 | 100 | 0.0003 | 0.0001 |
| SQRT Calcium | 1.70 | 1.64 | 0.42 - 2.65 | 79 | 1.62 | 1.63 | 0.44 - 2.61 | 148 | 0.1439 | 0.3068 |
| Log Aluminum* | 1.55 | 1.60 | 0.70 - 2.26 | 64 | 1.93 | 2.02 | 0.00 - 2.87 | 102 | 0.0001 | 0.0000 |
| Log DOC* | 0.50 | 0.51 | 0.11 - 0.99 | 47 | 0.31 | 0.34 | -0.40 - 0.78 | 57 | 0.0001 | 0.0000 |
| Latitude* | 46.0 | 45.7 | 45.0 - 47.4 | 81 | 46.5 | 46.7 | 44.7 - 48.5 | 157 | 0.0001 | 0.0000 |
| Log Lake Area | 1.65 | 1.58 | 0.28 - 3.71 | 80 | 1.59 | 1.57 | -0.05 - 3.58 | 151 | 0.5494 | 0.7689 |
| SQRT Max Depth | 4.40 | 4.38 | 1.10 - 8.83 | 77 | 4.26 | 4.36 | 1.00 - 9.35 | 137 | 0.6202 | 0.7808 |
| SQRT Mean Depth | 3.02 | 2.85 | 1.10 - 5.46 | 56 | 2.73 | 2.70 | 0.95 - 4.93 | 107 | 0.0753 | 0.1199 |
| Elevation* | 403 | 414 | 207 - 534 | 54 | 307 | 305 | 188 - 488 | 105 | 0.0001 | 0.0000 |
| Log MEI* | 0.49 | 0.41 | -0.22 - 1.28 | 54 | 0.61 | 0.57 | -0.15 - 1.47 | 88 | 0.0477 | 0.0385 |
| SQRT (# Species +1)[a]* | 3.44 | 3.39 | 2.24 - 5.20 | 40 | 3.01 | 3.00 | 1.41 - 4.69 | 28 | 0.0119 | 0.0176 |

[a]in lakes with pH ≥ 6.0

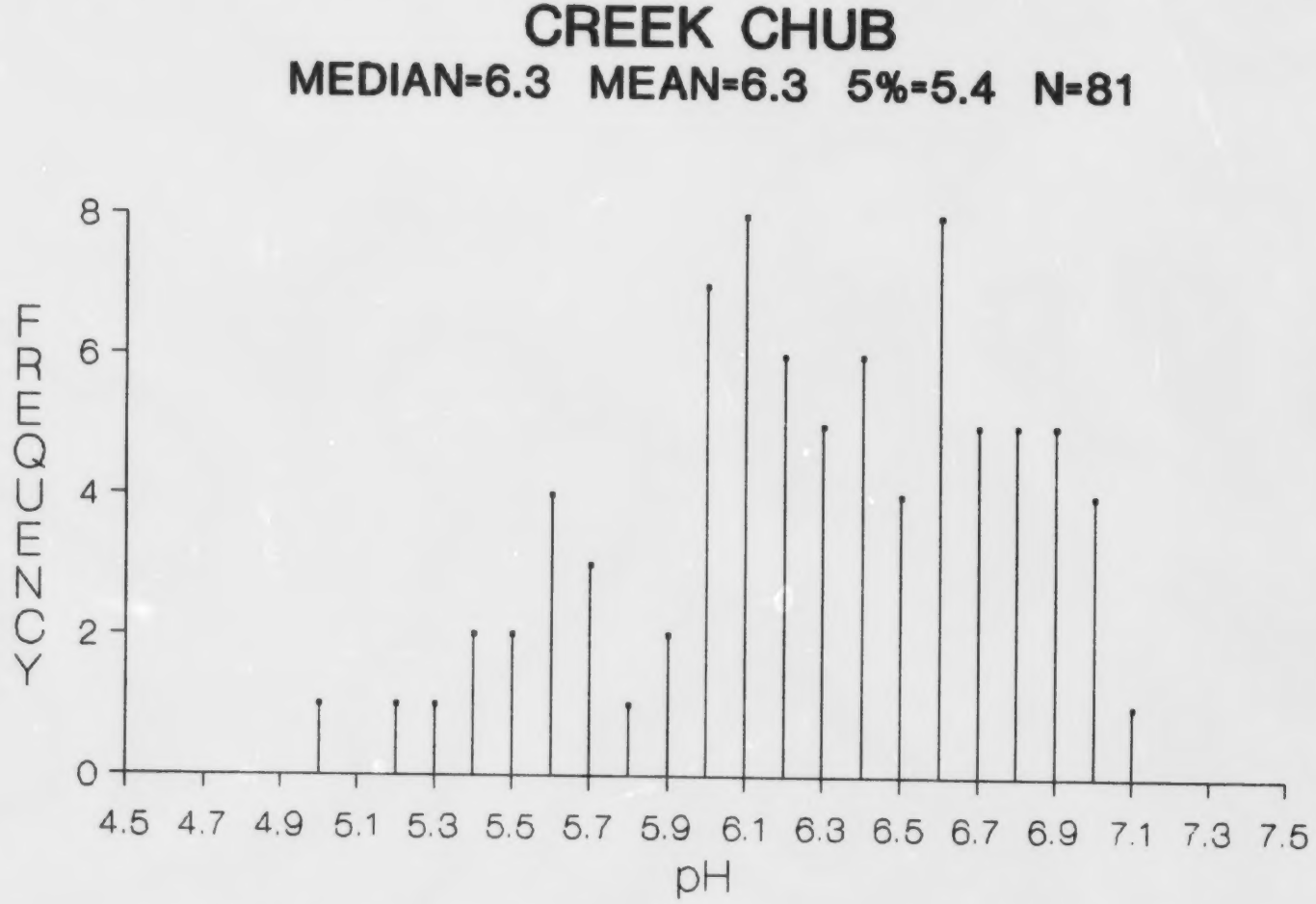


FIGURE 22. pH distribution of acid-sensitive lakes in which the creek chub was found.

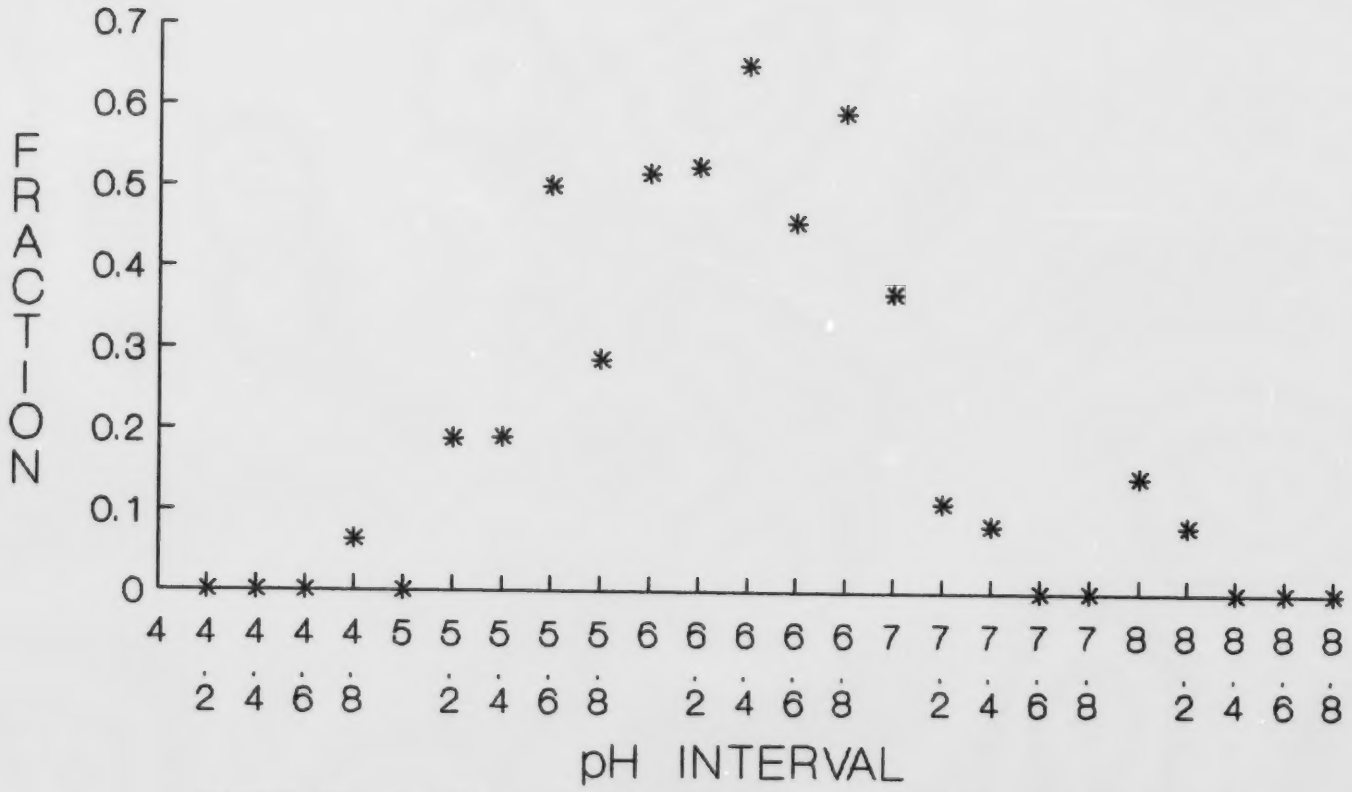


FIGURE 23. Fraction of surveyed lakes in south-central Ontario in which the creek chub was found, by pH interval of 0.2 unit.

BROOK STICKLEBACK

The brook stickleback was found in acid-sensitive lakes in both northwestern and south-central Ontario (Fig. 24). Lakes in which the species was present were at significantly higher elevations, and had significantly higher pH values and more fish species than lakes in which it was absent (Table 7). The species is acid-tolerant, with 23% of inhabited acid-sensitive lakes at pH < 6.0 and a pH threshold for extirpation in the range 5.1 - 5.3 (Fig. 25). In a set of 138 lakes in Wisconsin the pH distribution for this species extended to about 5.4 (N = 10) (Rahel and Magnuson 1983).

The occurrence of brook stickleback in our surveyed lakes gradually declines with decreasing pH at pH values below 6.0 (Fig. 26) due to adverse effects associated with low pH and/or some other factor or factors correlated with pH.

The lack of an abrupt drop in the occurrence of brook stickleback at an appropriate pH makes the species unsuitable as an early indicator of changes in the fish community due to acidification.

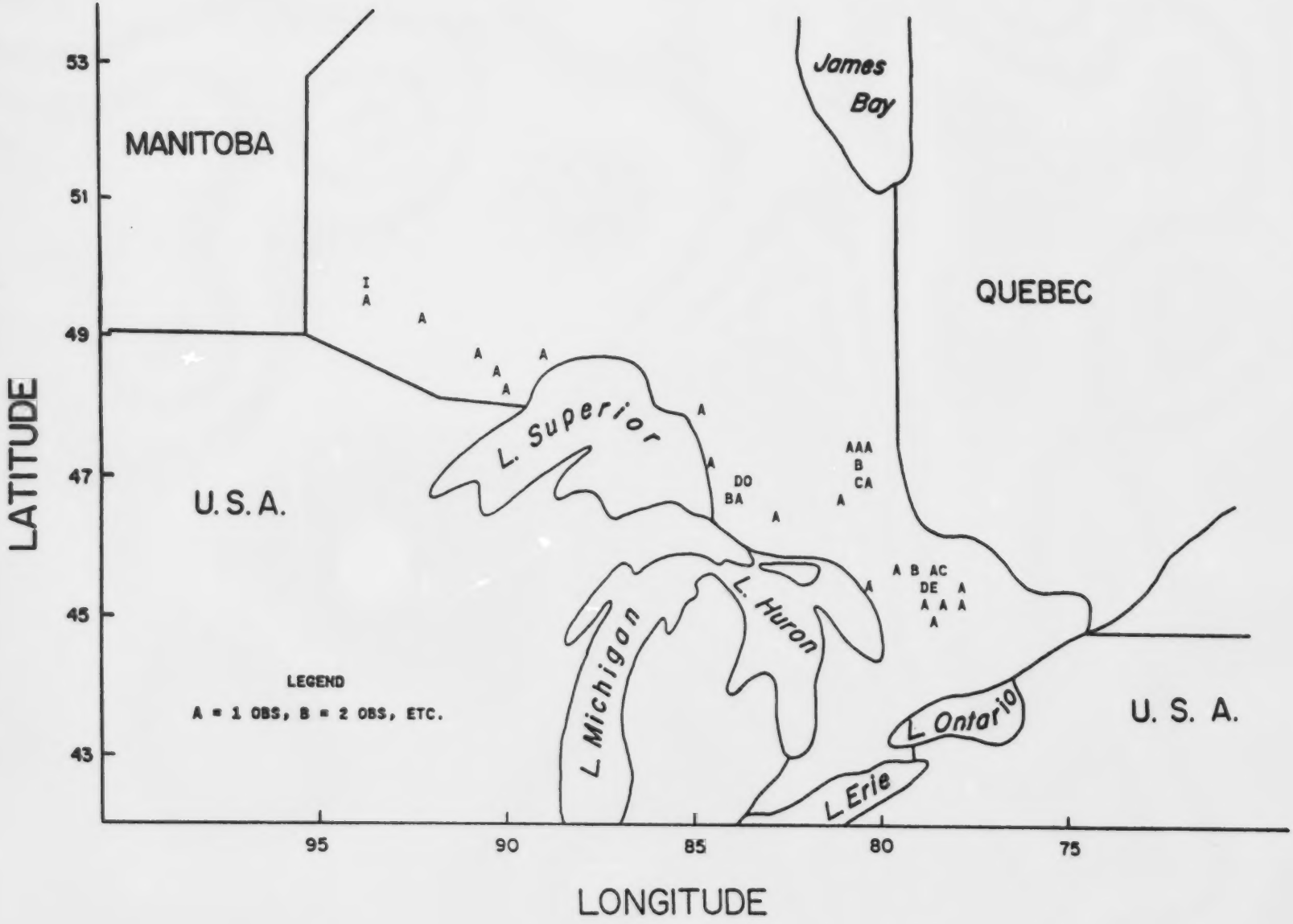


FIGURE 24. Location of acid-sensitive lakes in which the brook stickleback was found.

Table 7. Differences between the acid-sensitive lakes in which the brook stickleback was present and absent. Significance probabilities are given for T-tests and Wilcoxon rank sum tests. Asterisks indicate variables with significant differences at the 5% level.

| | PRESENT | | | | ABSENT | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Variable | Mean | Median | Range | N | Mean | Median | Range | N | T-Test | Wilcoxon Rank Sum Test |
| pH* | 6.3 | 6.4 | 4.7 - 7.3 | 73 | 5.9 | 6.1 | 3.8 - 7.4 | 259 | 0.0001 | 0.0030 |
| Log Alkalinity+5 | 0.89 | 0.91 | 0.58 - 1.17 | 70 | 0.88 | 0.89 | 0.37 - 1.17 | 192 | 0.4797 | 0.4533 |
| SQRT Calcium | 1.60 | 1.61 | 0.45 - 2.51 | 67 | 1.56 | 1.52 | 0.42 - 2.65 | 246 | 0.3913 | 0.1603 |
| Log Aluminum | 1.69 | 1.70 | 0.85 - 2.59 | 45 | 1.79 | 1.88 | 0.00 - 2.87 | 126 | 0.2316 | 0.1383 |
| Log DOC | 0.57 | 0.56 | -0.40 - 1.10 | 43 | 0.66 | 0.70 | -0.22 - 1.33 | 151 | 0.1241 | 0.0925 |
| Latitude | 47.1 | 47.1 | 45.0 - 49.7 | 73 | 47.3 | 46.8 | 44.7 - 49.8 | 259 | 0.1974 | 0.3943 |
| Log Lake Area | 1.58 | 1.48 | 0.38 - 3.71 | 72 | 1.47 | 1.41 | -0.05 - 3.81 | 250 | 0.2634 | 0.3571 |
| SQRT Max Depth | 4.14 | 3.95 | 1.10 - 8.53 | 61 | 4.40 | 4.38 | 1.00 - 9.35 | 162 | 0.4143 | 0.3275 |
| SQRT Mean Depth | 2.87 | 2.73 | 0.84 - 5.22 | 42 | 2.81 | 2.76 | 0.95 - 5.46 | 130 | 0.7066 | 0.9092 |
| Elevation* | 397 | 422 | 213 - 534 | 41 | 328 | 350 | 188 - 503 | 127 | 0.0001 | 0.0002 |
| Log MEI | 0.56 | 0.56 | -0.10 - 1.36 | 40 | 0.56 | 0.51 | -0.22 - 1.47 | 111 | 0.9862 | 0.9697 |
| SQRT (# Species +1)[a]* | 3.18 | 3.16 | 1.73 - 5.20 | 35 | 2.66 | 2.65 | 1.00 - 4.90 | 106 | 0.0023 | 0.0032 |

[a]in lakes with pH ≥ 6.0

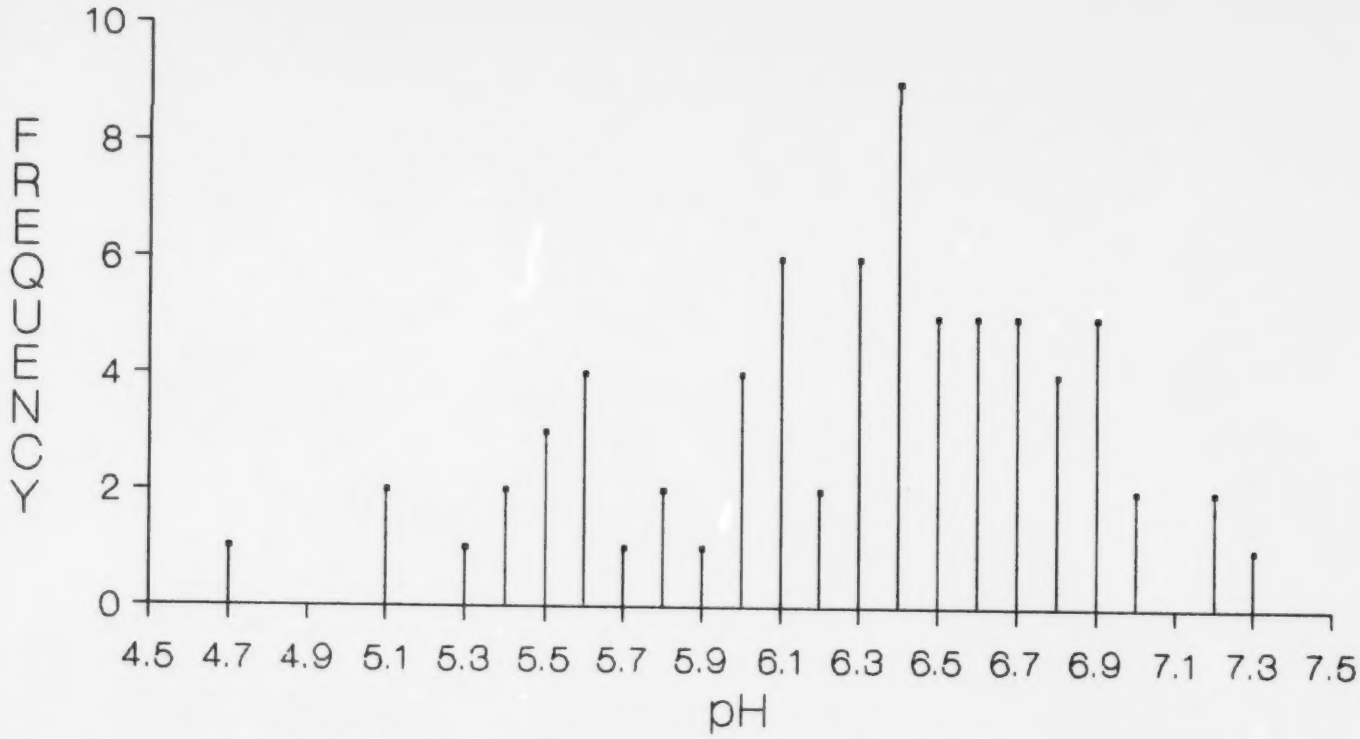


FIGURE 25. pH distribution of acid-sensitive lakes in which the brook stickleback was found.

# BROOK STICKLEBACK

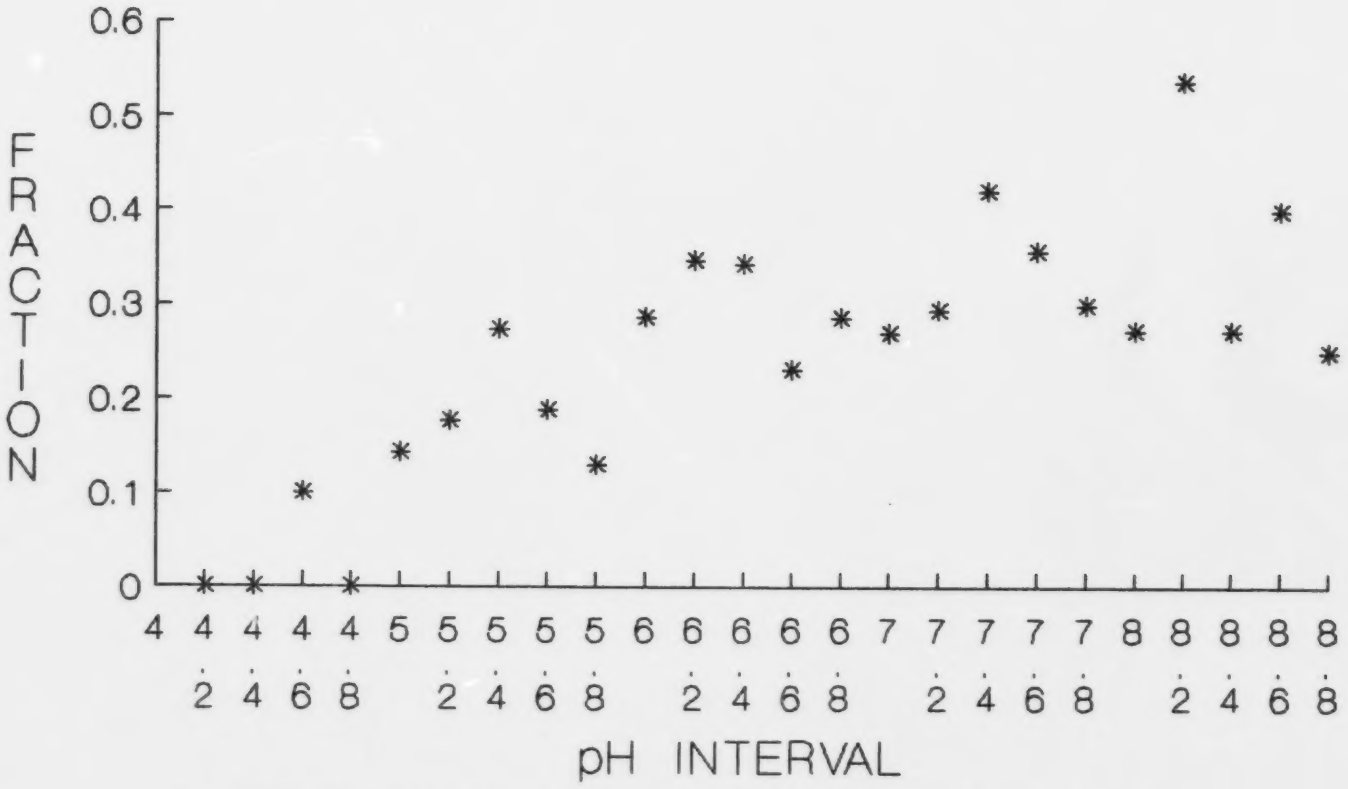


FIGURE 26. Fraction of surveyed lakes in which the brook stickleback was found, by pH interval of 0.2 unit.

GOLDEN SHINER

The golden shiner was found in acid-sensitive lakes almost exclusively in south-central Ontario (Fig. 27). Lakes in which the species was present were significantly larger, and had greater maximum depths, lower aluminum concentrations, and more fish species than lakes in which it was absent (Table 8). The golden shiner is acid-tolerant, with 40% of inhabited acid-sensitive lakes at pH < 6.0 and a pH threshold for extirpation in the range 4.7 - 4.9 (Fig. 28). In a set of 138 lakes in Wisconsin the pH distribution for this species extended to about 5.2 (N = 63) (Rahel and Magnuson 1983).

The occurrence of golden shiner in our surveyed lakes in south-central Ontario remains at a high average level down to pH 5.0 (29% for pH 5.0 - 5.6) (Fig. 29). Below pH 5.0 occurrence drops to an average 8% for pH 4.6-4.8, and then to 0% at lower pH values.

Since the golden shiner is present in a substantial fraction of acidic lakes down to pH 5.0, it is unsuitable as an early indicator of changes in the fish community due to acidification in the usual sense. However, because it seems to flourish in acidic waters, a population of golden shiner may signal early changes in the fish community due to acidification by

increasing in abundance, just as the pearl dace did in experimentally acidified Lake 223 (Mills et al. 1987). However, unlike the more ubiquitous pearl dace, the golden shiner is common only in south-central Ontario.

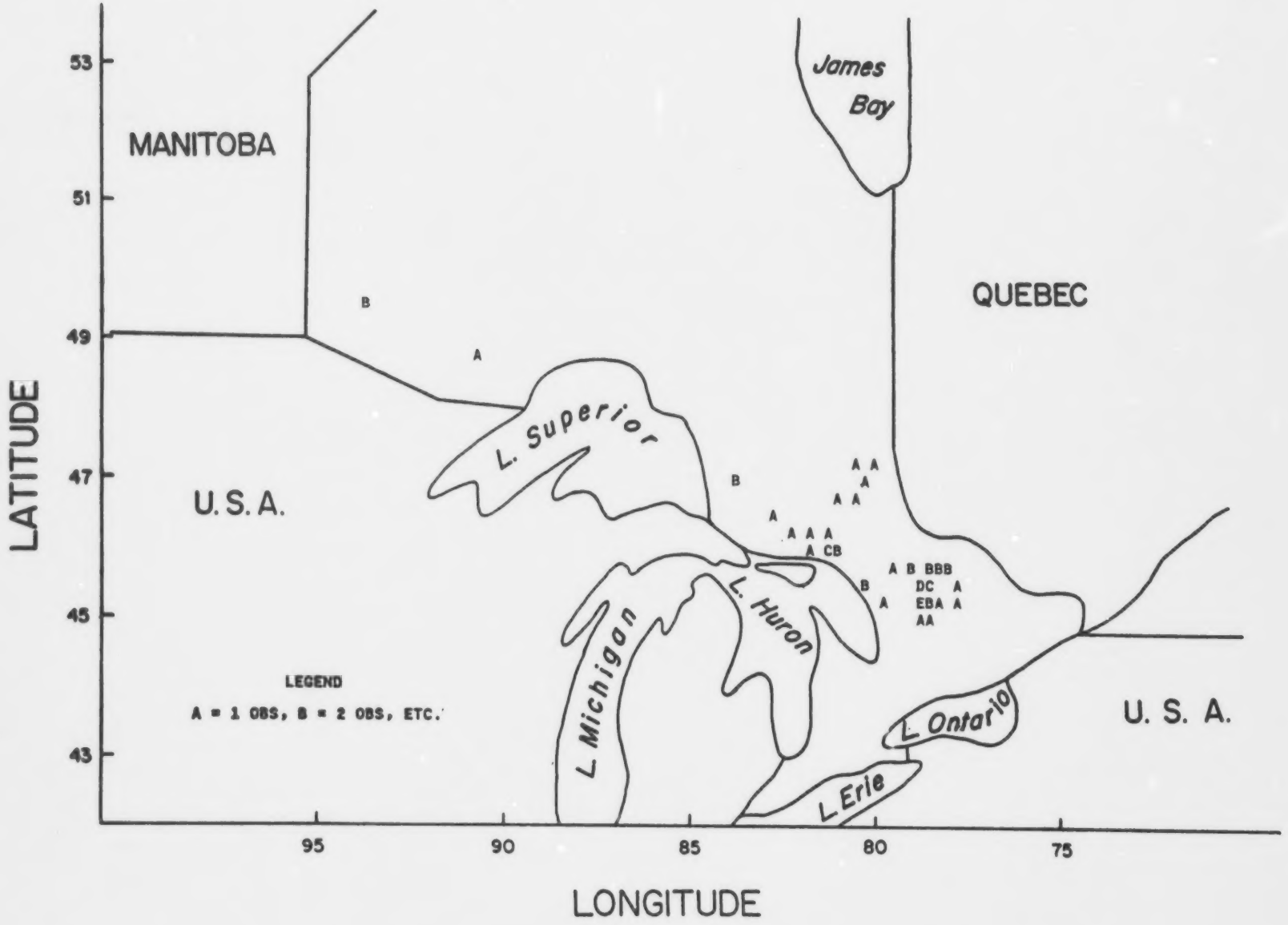


FIGURE 27. Location of acid-sensitive lakes in which the golden shiner was found.

**Table 8.** Differences between the acid-sensitive lakes in south-central Ontario in which the golden shiner was present and absent. Significance probabilities are given for T-tests and Wilcoxon rank sum tests. Asterisks indicate variables with significant differences at the 5% level.

| | PRESENT | | | | ABSENT | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Variable | Mean | Median | Range | N | Mean | Median | Range | N | T-Test | Wilcoxon Rank Sum Test |
| pH | 6.0 | 6.0 | 4.7 - 7.0 | 50 | 5.8 | 5.9 | 3.8 - 7.2 | 188 | 0.0771 | 0.2417 |
| Log Alkalinity+5 | 0.86 | 0.82 | 0.58 - 1.15 | 37 | 0.85 | 0.82 | 0.37 - 1.17 | 139 | 0.8994 | 0.5973 |
| SQRT Calcium | 1.70 | 1.67 | 0.53 - 2.65 | 50 | 1.64 | 1.62 | 0.42 - 2.61 | 177 | 0.2623 | 0.4229 |
| Log Aluminum* | 1.59 | 1.62 | 0.00 - 2.59 | 43 | 1.85 | 1.92 | 0.70 - 2.87 | 123 | 0.0015 | 0.0019 |
| Log DOC | 0.44 | 0.46 | -0.40 - 0.78 | 32 | 0.38 | 0.41 | -0.22 - 0.99 | 72 | 0.2070 | 0.1795 |
| Latitude* | 45.8 | 45.7 | 45.0 - 47.3 | 50 | 46.5 | 46.7 | 44.7 - 48.5 | 188 | 0.0001 | 0.0000 |
| Log Lake Area* | 2.14 | 2.10 | 0.95 - 3.71 | 48 | 1.47 | 1.41 | -0.05 - 3.30 | 183 | 0.0001 | 0.0000 |
| SQRT Max Depth* | 5.07 | 4.93 | 1.55 - 9.35 | 47 | 4.10 | 4.12 | 1.00 - 8.83 | 167 | 0.0013 | 0.0036 |
| SQRT Mean Depth | 2.85 | 2.74 | 0.95 - 4.93 | 47 | 2.83 | 2.74 | 1.00 - 5.46 | 116 | 0.8688 | 0.9927 |
| Elevation | 356 | 372 | 188 - 534 | 46 | 333 | 335 | 189 - 488 | 113 | 0.1749 | 0.2473 |
| Log MEI | 0.57 | 0.53 | -0.15 - 1.42 | 46 | 0.56 | 0.52 | -0.22 - 1.47 | 96 | 0.8946 | 0.9635 |
| SQRT (# Species +1)[a]* | 3.60 | 3.61 | 2.00 - 5.20 | 27 | 3.03 | 3.00 | 1.41 - 4.36 | 41 | 0.0008 | 0.0008 |

[a]in lakes with pH ≥ 6.0

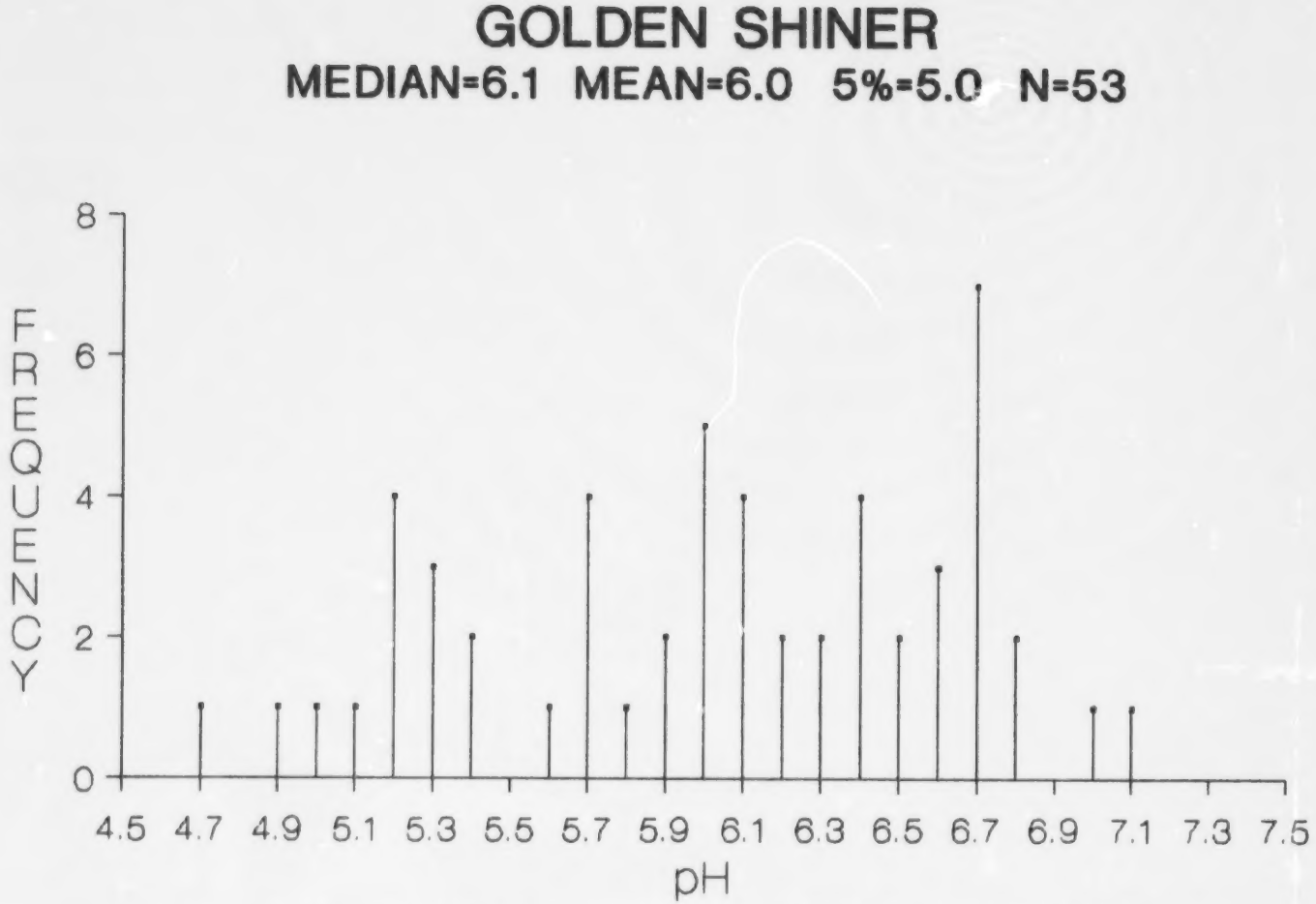


FIGURE 28. pH distribution of acid-sensitive lakes in which the golden shiner was found.

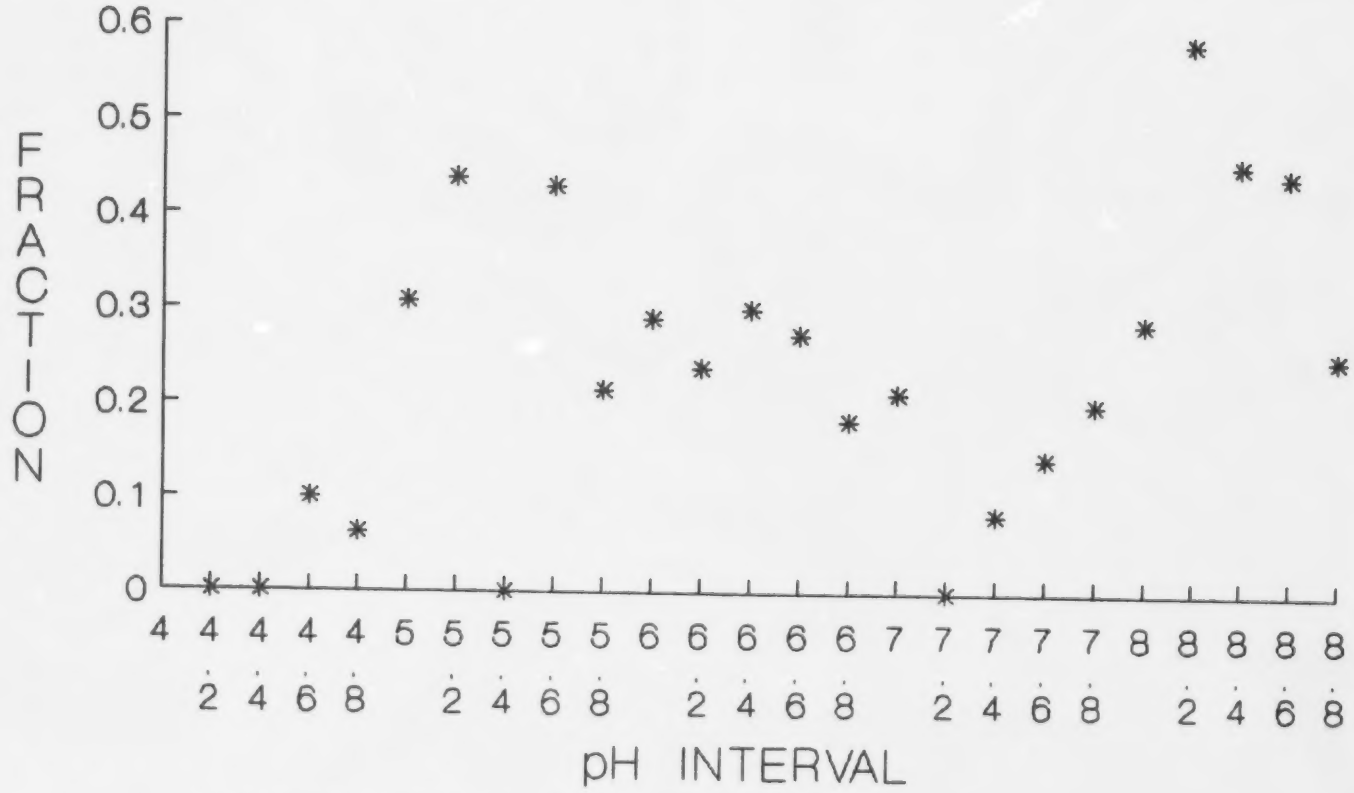


FIGURE 29. Fraction of surveyed lakes in south-central Ontario in which the golden shiner was found, by pH interval of 0.2 unit.

IOWA DARTER

The Iowa darter was found in acid-sensitive lakes in both northwestern and south-central Ontario (Fig. 30). Lakes in which the species was present were significantly larger and had greater maximum depths than lakes in which it was absent (Table 9). Inhabited lakes had significantly higher values for pH, alkalinity, and calcium, and lower values for aluminum compared with uninhabited lakes (Table 9). A significantly higher number of fish species were present in lakes with Iowa darter than in lakes without Iowa darter (Table 9). The species is moderately acid-tolerant, with 25% of inhabited acid-sensitive lakes at pH < 6.0 and a pH threshold for extirpation of about 5.4 (Fig. 31). In a set of 138 lakes in Wisconsin the pH distribution for this species extended to only about 6.2 (N = 24) (Rahel and Magnuson 1983).

The occurrence of Iowa darter in our surveyed lakes is highest for high pH lakes, averaging 67% for pH 7.6-8.6 (Fig. 32). Occurrence averages 22% for pH 5.4 - 7.0 and drops to near 0% below pH 5.4.

pH related changes in populations of Iowa darter can only be reliably expected below pH 5.4, thereby making the species unsuitable as an early indicator of change in the fish community due to acidification.

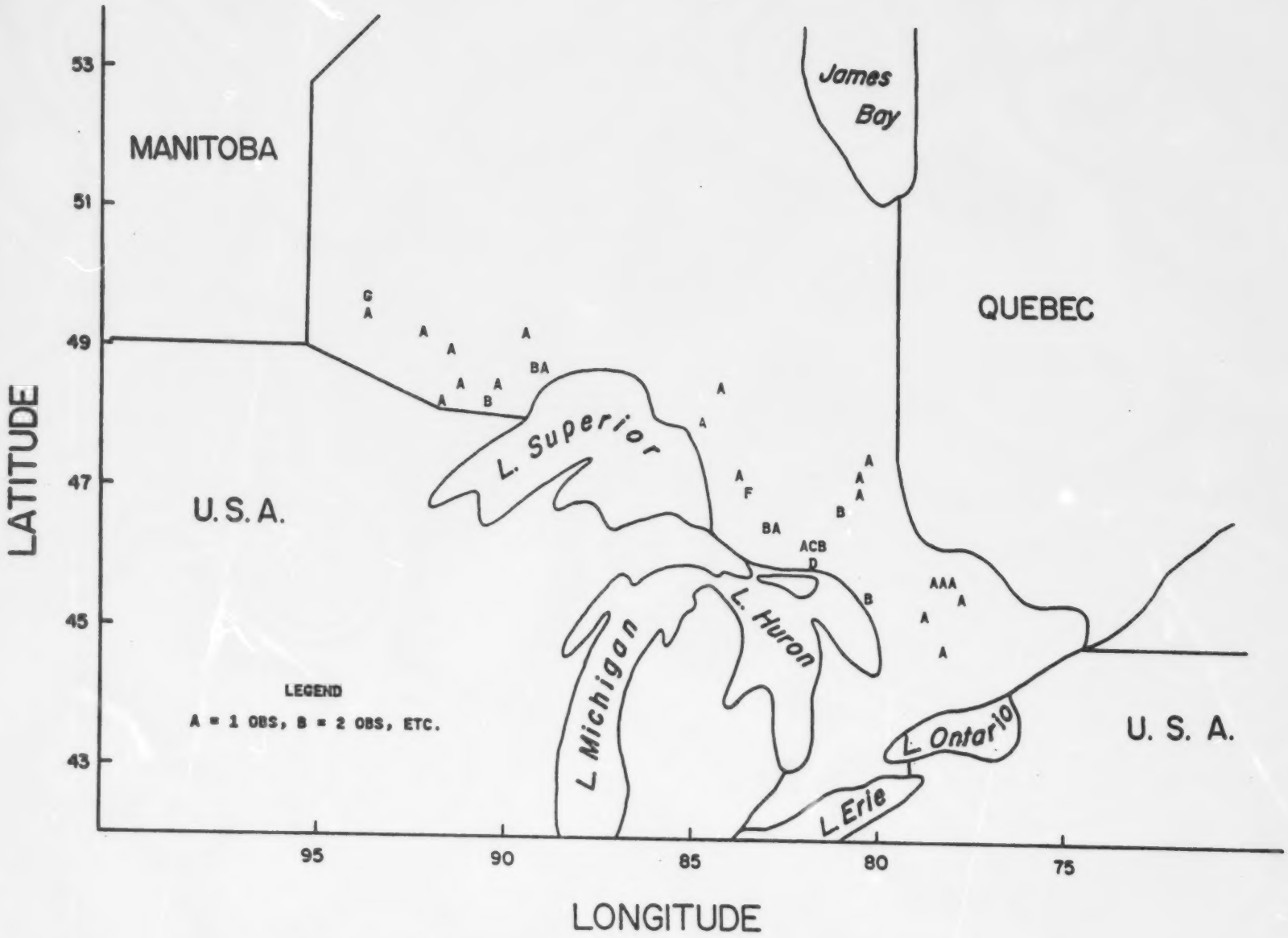


FIGURE 30. Location of acid-sensitive lakes in which the Iowa darter was found.

Table 9. Differences between the acid-sensitive lakes in which the Iowa darter was present and absent. Significance probabilities are given for T-tests and Wilcoxon rank sum tests. Asterisks indicate variables with significant differences at the 5% level.

| | PRESENT | | | | ABSENT | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Variable | Mean | Median | Range | N | Mean | Median | Range | N | T-Test | Wilcoxon Rank Sum Test |
| pH* | 6.3 | 6.3 | 5.1 - 7.1 | 56 | 5.9 | 6.1 | 3.8 - 7.4 | 276 | 0.0001 | 0.0041 |
| Log Alkalinity+5* | 0.94 | 0.96 | 0.67 - 1.16 | 40 | 0.87 | 0.87 | 0.37 - 1.17 | 222 | 0.0072 | 0.0047 |
| SQRT Calcium* | 1.75 | 1.77 | 0.42 - 2.65 | 48 | 1.54 | 1.52 | 0.44 - 2.37 | 265 | 0.0037 | 0.0004 |
| Log Aluminum* | 1.57 | 1.58 | 0.95 - 2.28 | 27 | 1.80 | 1.88 | 0.00 - 2.87 | 144 | 0.0173 | 0.0106 |
| Log DOC | 0.72 | 0.78 | 0.28 - 1.10 | 30 | 0.63 | 0.63 | -0.40 - 1.33 | 164 | 0.0789 | 0.1895 |
| Latitude | 47.3 | 47.1 | 44.7 - 49.7 | 56 | 47.2 | 46.9 | 45.0 - 49.8 | 276 | 0.6512 | 0.4498 |
| Log Lake Area* | 1.86 | 1.83 | 0.38 - 3.81 | 54 | 1.42 | 1.37 | -0.05 - 3.58 | 268 | 0.0005 | 0.0003 |
| SQRT Max Depth* | 5.00 | 4.69 | 1.34 - 8.83 | 45 | 4.17 | 4.17 | 1.00 - 9.35 | 178 | 0.0069 | 0.0145 |
| SQRT Mean Depth | 3.04 | 2.97 | 0.84 - 5.46 | 40 | 2.76 | 2.71 | 0.95 - 4.93 | 132 | 0.1516 | 0.1311 |
| Elevation | 330 | 344 | 188 - 503 | 38 | 350 | 366 | 189 - 534 | 130 | 0.2589 | 0.2047 |
| Log MEI | 0.53 | 0.43 | -0.22 - 1.47 | 37 | 0.57 | 0.54 | -0.15 - 1.45 | 114 | 0.5296 | 0.3123 |
| SQRT (# Species +1)[a]* | 3.31 | 3.16 | 1.73 - 5.20 | 37 | 2.61 | 2.65 | 1.00 - 4.69 | 104 | 0.0001 | 0.0001 |

[a]in lakes with pH ≥ 6.0

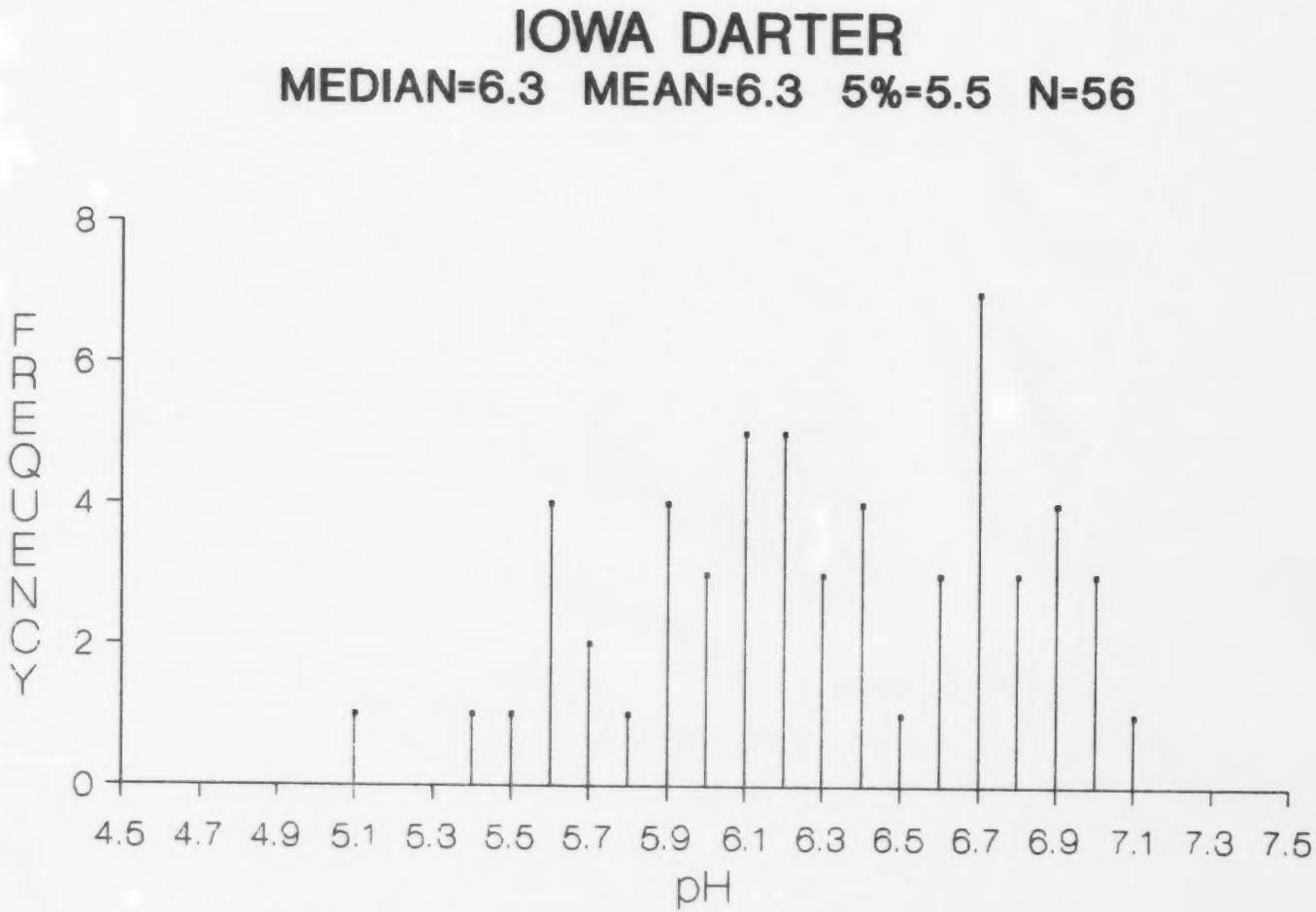


FIGURE 31. pH distribution of acid-sensitive lakes in which the Iowa darter was found.

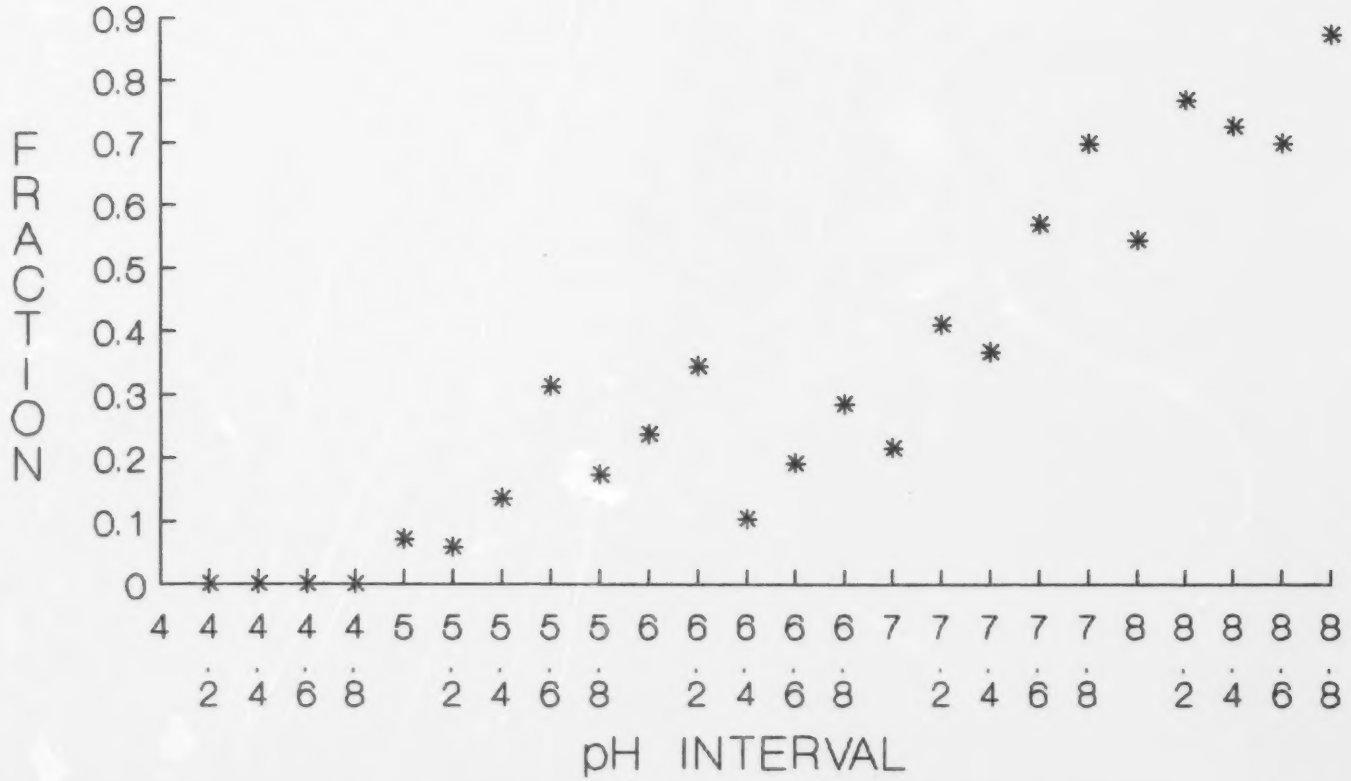


FIGURE 32. Fraction of surveyed lakes in which the Iowa darter was found, by pH interval of 0.2 unit.

FINESCALE DACE

The finescale dace was found in acid-sensitive lakes in both northwestern and south-central Ontario (Fig. 33). However, there was a significantly higher rate of occurrence in the northern latitudes (Table 10). Inhabited lakes had significantly higher values for elevation, maximum depth, pH, and dissolved organic carbon, and lower values for calcium and aluminum compared with uninhabited lakes (Table 10). The species is moderately acid-tolerant, with 21% of inhabited acid sensitive lakes at pH < 6.0 and a pH threshold for extirpation of about 5.4 (Fig. 34).

The occurrence of finescale dace in our surveyed lakes gradually declines with pH without any large, sudden drops (Fig. 35).

The lack of an abrupt drop in the occurrence of finescale dace at an appropriate pH makes the species unsuitable as an early indicator of changes in the fish community due to acidification.

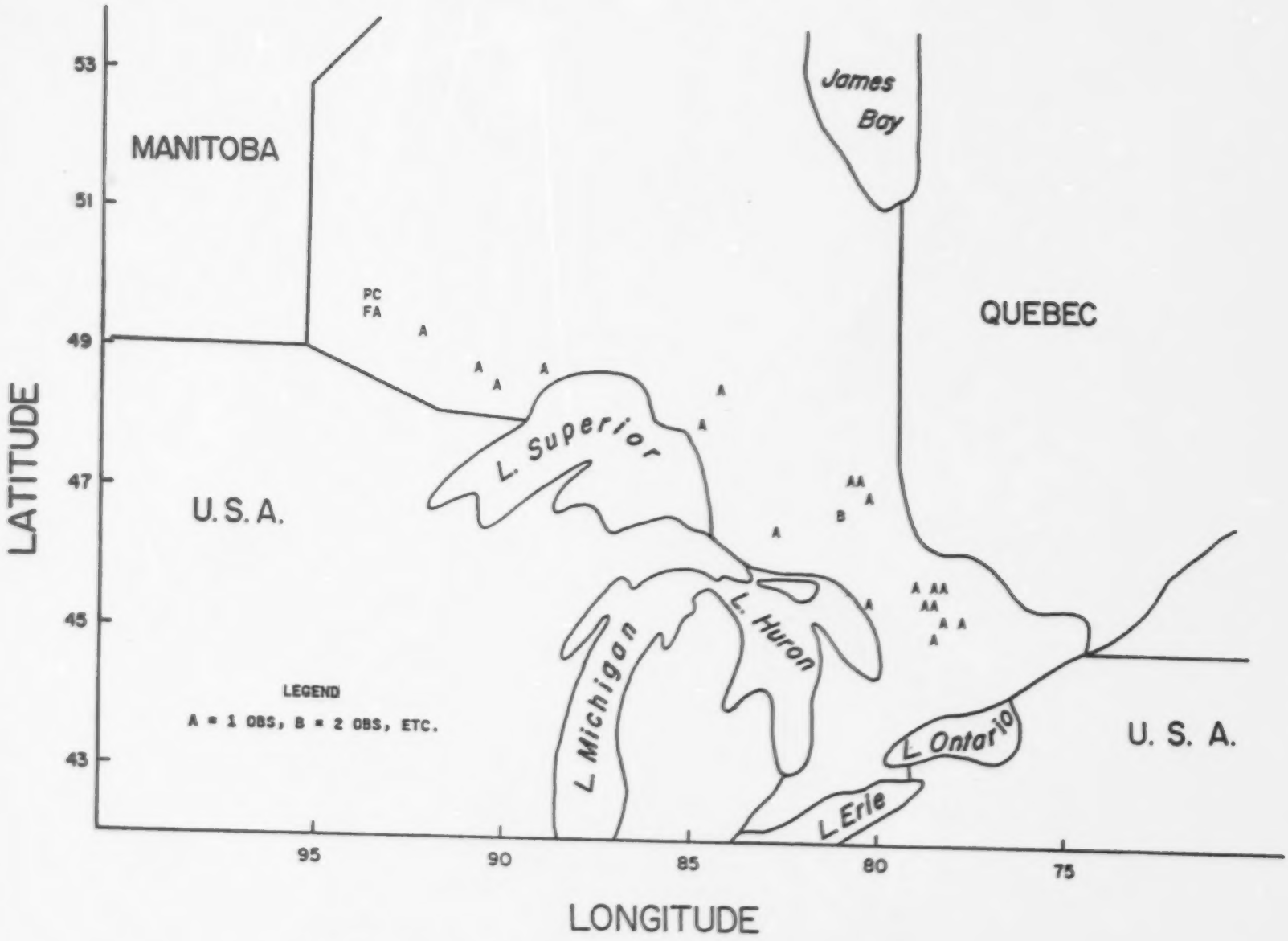


FIGURE 33. Location of acid-sensitive lakes in which the finescale dace was found.

Table 10. Differences between the acid-sensitive lakes in which the finescale dace was present and absent. Significance probabilities are given for T-tests and Wilcoxon rank sum tests. Asterisks indicate variables with significant differences at the 5% level.

| | PRESENT | | | | ABSENT | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Variable | Mean | Median | Range | N | Mean | Median | Range | N | T-Test | Wilcoxon Rank Sum Test |
| pH* | 6.2 | 6.3 | 4.7 - 7.4 | 47 | 6.0 | 6.1 | 3.8 - 7.3 | 285 | 0.0028 | 0.0394 |
| Log Alkalinity+5 | 0.90 | 0.93 | 0.58 - 1.14 | 42 | 0.88 | 0.88 | 0.37 - 1.17 | 220 | 0.4738 | 0.4777 |
| SQRT Calcium* | 1.45 | 1.41 | 0.53 - 2.51 | 43 | 1.59 | 1.58 | 0.42 - 2.65 | 270 | 0.0259 | 0.0019 |
| Log Aluminum* | 1.53 | 1.41 | 1.00 - 2.59 | 15 | 1.79 | 1.88 | 0.00 - 2.87 | 156 | 0.0429 | 0.0239 |
| Log DOC* | 0.81 | 0.94 | -0.40 - 1.33 | 39 | 0.60 | 0.59 | -0.22 - 1.31 | 155 | 0.0005 | 0.0002 |
| Latitude* | 48.4 | 49.6 | 45.0 - 49.7 | 47 | 47.1 | 46.8 | 44.7 - 49.8 | 285 | 0.0001 | 0.0000 |
| Log Lake Area | 1.53 | 1.28 | 0.45 - 3.71 | 46 | 1.49 | 1.43 | -0.05 - 3.81 | 276 | 0.7247 | 0.9666 |
| SQRT Max Depth* | 5.06 | 5.06 | 1.34 - 8.37 | 20 | 4.27 | 4.24 | 1.00 - 9.35 | 203 | 0.0689 | 0.0471 |
| SQRT Mean Depth | 2.79 | 2.80 | 0.84 - 4.56 | 20 | 2.83 | 2.74 | 0.95 - 5.46 | 152 | 0.8250 | 0.9372 |
| Elevation* | 407 | 408 | 336 - 488 | 18 | 338 | 358 | 188 - 534 | 150 | 0.0001 | 0.0051 |
| Log MEI | 0.62 | 0.57 | 0.26 - 1.36 | 18 | 0.55 | 0.52 | -0.22 - 1.47 | 133 | 0.4688 | 0.5256 |
| SQRT (# Species +1)[a] | 2.78 | 2.83 | 1.41 - 5.20 | 37 | 2.80 | 2.83 | 1.00 - 4.90 | 104 | 0.9344 | 0.7834 |

[a]in lakes with pH ≥ 6.0

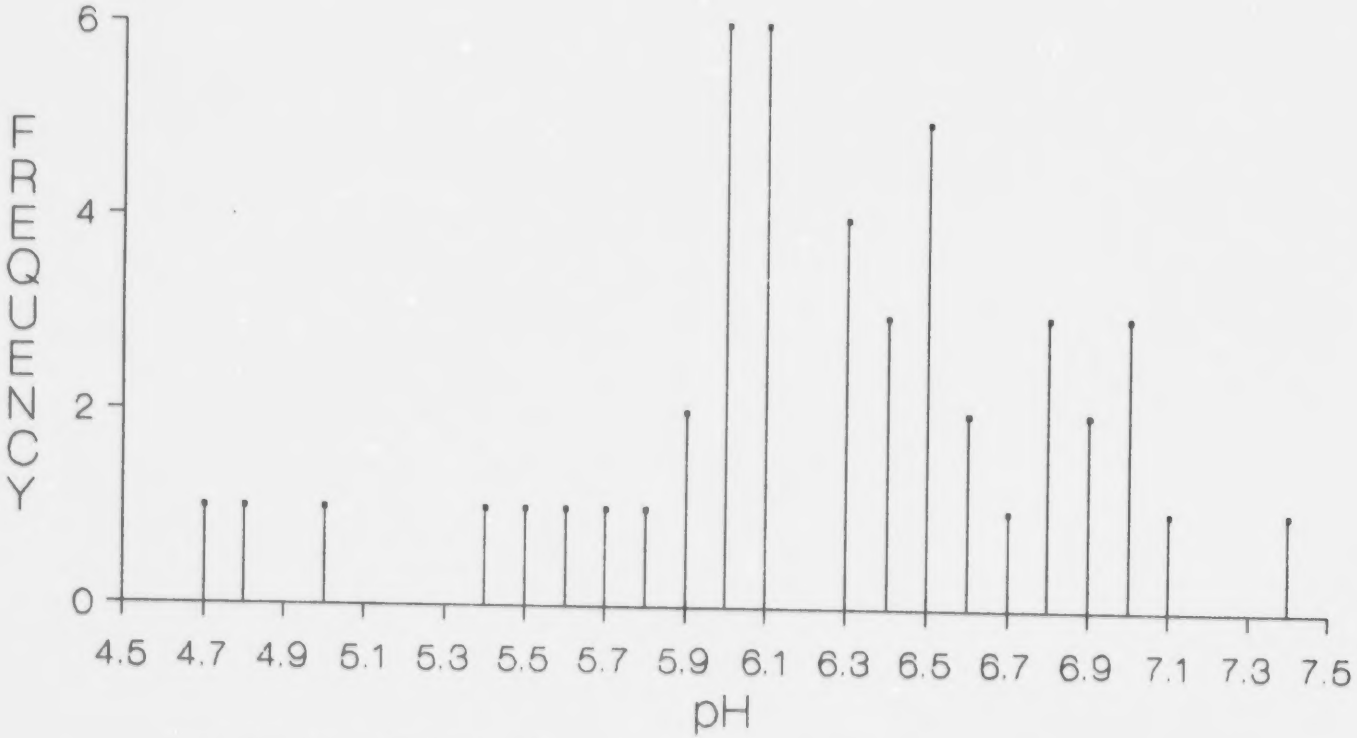


FIGURE 34. pH distribution of acid-sensitive lakes in which the finescale dace was found.

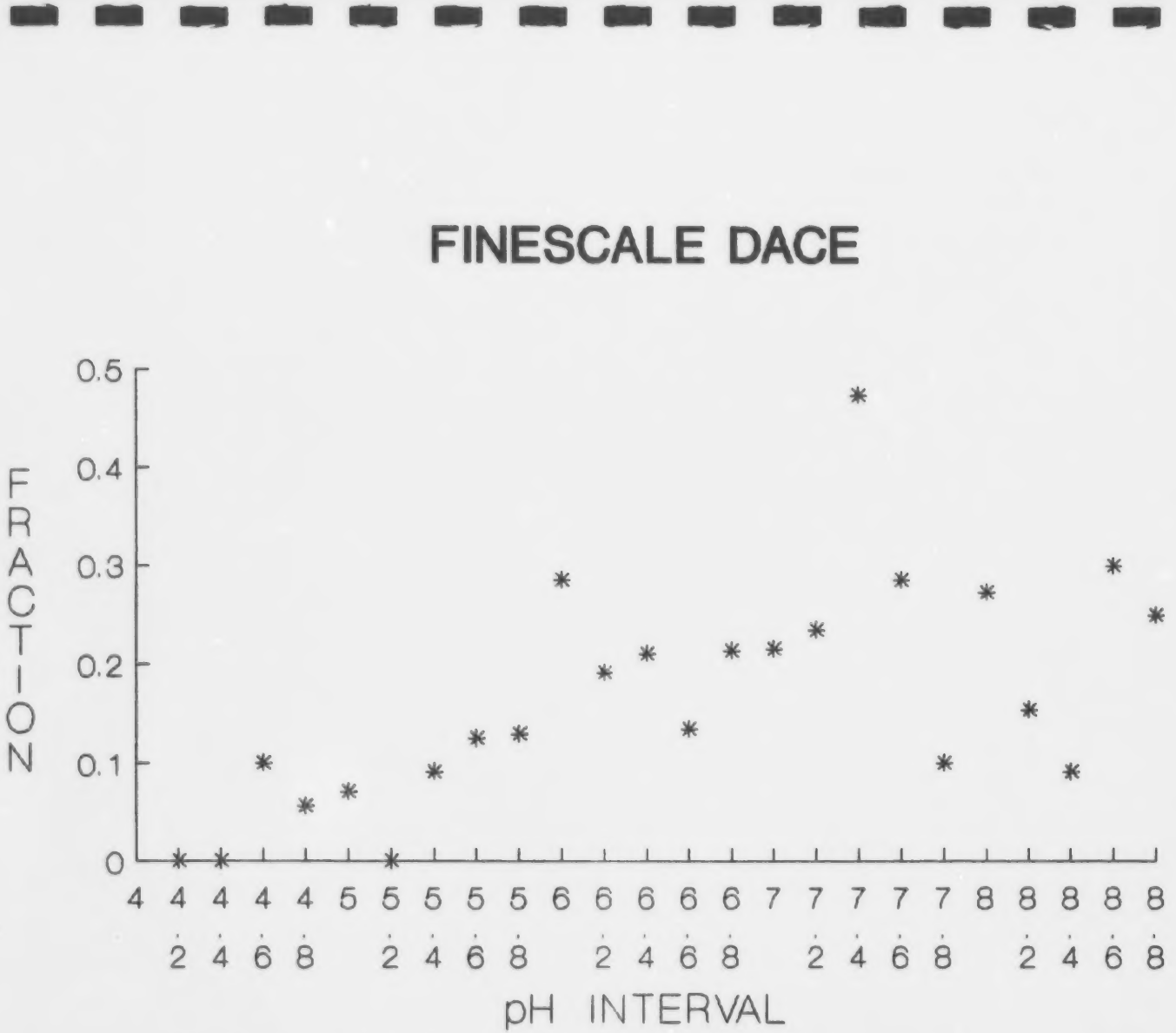


FIGURE 35. Fraction of surveyed lakes in which the finescale dace was found, by pH interval of 0.2 unit.

COMMON SHINER

The common shiner was found in acid-sensitive lakes almost exclusively in south-central Ontario (Fig. 36). Lakes in which the species was present were significantly larger, with greater mean depths, and at higher elevations than lakes in which the species was absent (Table 11). Inhabited lakes had significantly higher values for pH, alkalinity, calcium, and dissolved organic carbon, and lower values for aluminum (Table 11). A significantly higher number of fish species were present in lakes with common shiner than in lakes without common shiner (Table 11). The species is acid-sensitive, with only 14% of inhabited acid-sensitive lakes at pH < 6.0 and a pH threshold for extirpation in the range 5.4 - 5.8 (Fig. 37). In a set of 138 lakes in Wisconsin the pH distribution for this species extended to only 6.2 (N = 31) (Rahel and Magnuson 1983). In laboratory toxicity tests the survival of early life stages decreased below pH 5.9 (Holtze et al. 1988).

The occurrence of common shiner in our surveyed lakes in south-central Ontario drops from an average 40% for pH 6.0 - 7.2 to an average 13% for pH 5.2 - 5.8 (Fig. 38), indicating that there is a high probability that a particular population will exhibit changes associated with pH at pH < 6.0.

The common shiner is a good candidate for consideration as an early indicator of changes in the fish community due to acidification in its restricted range of south-central Ontario.

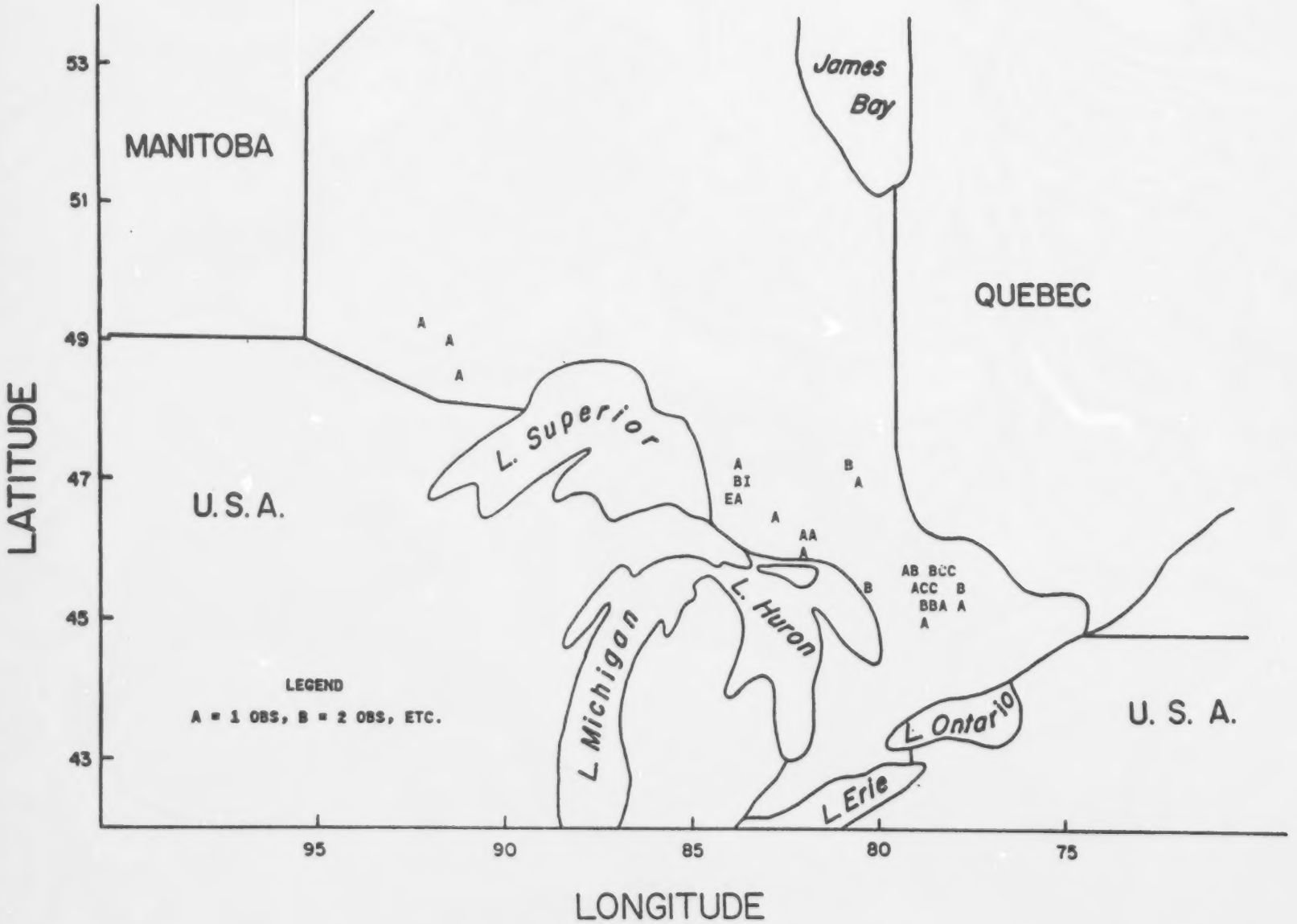


FIGURE 36. Location of acid-sensitive lakes in which the common shiner was found.

**Table 11.** Differences between the acid-sensitive lakes in south-central Ontario in which the common shiner was present and absent. Significance probabilities are given for T-tests and Wilcoxon rank sum tests. Asterisks indicate variables with significant differences at the 5% level.

| | PRESENT | | | | ABSENT | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Variable | Mean | Median | Range | N | Mean | Median | Range | N | T-Test | Wilcoxon Rank Sum Test |
| pH* | 6.4 | 6.4 | 5.4 - 7.0 | 55 | 5.7 | 5.6 | 3.8 - 7.2 | 183 | 0.0001 | 0.0000 |
| Log Alkalinity+5* | 0.93 | 0.93 | 0.69 - 1.16 | 50 | 0.82 | 0.78 | 0.37 - 1.17 | 126 | 0.0001 | 0.0000 |
| SQRT Calcium* | 1.78 | 1.73 | 1.34 - 2.61 | 53 | 1.61 | 1.61 | 0.42 - 2.65 | 174 | 0.0007 | 0.0064 |
| Log Aluminum* | 1.51 | 1.45 | 0.70 - 2.13 | 43 | 1.88 | 1.94 | 0.00 - 2.87 | 123 | 0.0001 | 0.0000 |
| Log DOC* | 0.50 | 0.50 | 0.04 - 0.99 | 30 | 0.35 | 0.39 | -0.40 - 1.78 | 74 | 0.0012 | 0.0044 |
| Latitude* | 46.2 | 45.8 | 45.0 - 47.3 | 55 | 46.4 | 46.2 | 44.7 - 48.5 | 183 | 0.0130 | 0.0138 |
| Log Lake Area* | 1.88 | 1.94 | 0.28 - 3.71 | 55 | 1.52 | 1.49 | -0.05 - 3.06 | 176 | 0.0042 | 0.0065 |
| SQRT Max Depth | 4.61 | 4.52 | 1.10 - 9.35 | 55 | 4.21 | 4.12 | 1.00 - 8.83 | 159 | 0.2120 | 0.2446 |
| SQRT Mean Depth* | 3.18 | 3.12 | 1.10 - 5.22 | 40 | 2.72 | 2.70 | 0.95 - 5.46 | 123 | 0.0046 | 0.0090 |
| Elevation* | 380 | 396 | 189 - 534 | 38 | 327 | 335 | 188 - 492 | 121 | 0.0020 | 0.0040 |
| Log MEI | 0.48 | 0.45 | -0.10 - 1.47 | 38 | 0.59 | 0.57 | -0.22 - 1.45 | 104 | 0.0914 | 0.0607 |
| SQRT (# Species +1)[a]* | 3.64 | 3.61 | 2.24 - 5.20 | 31 | 2.94 | 3.00 | 1.41 - 4.00 | 37 | 0.0001 | 0.0000 |

[a]in lakes with pH ≥ 6.0

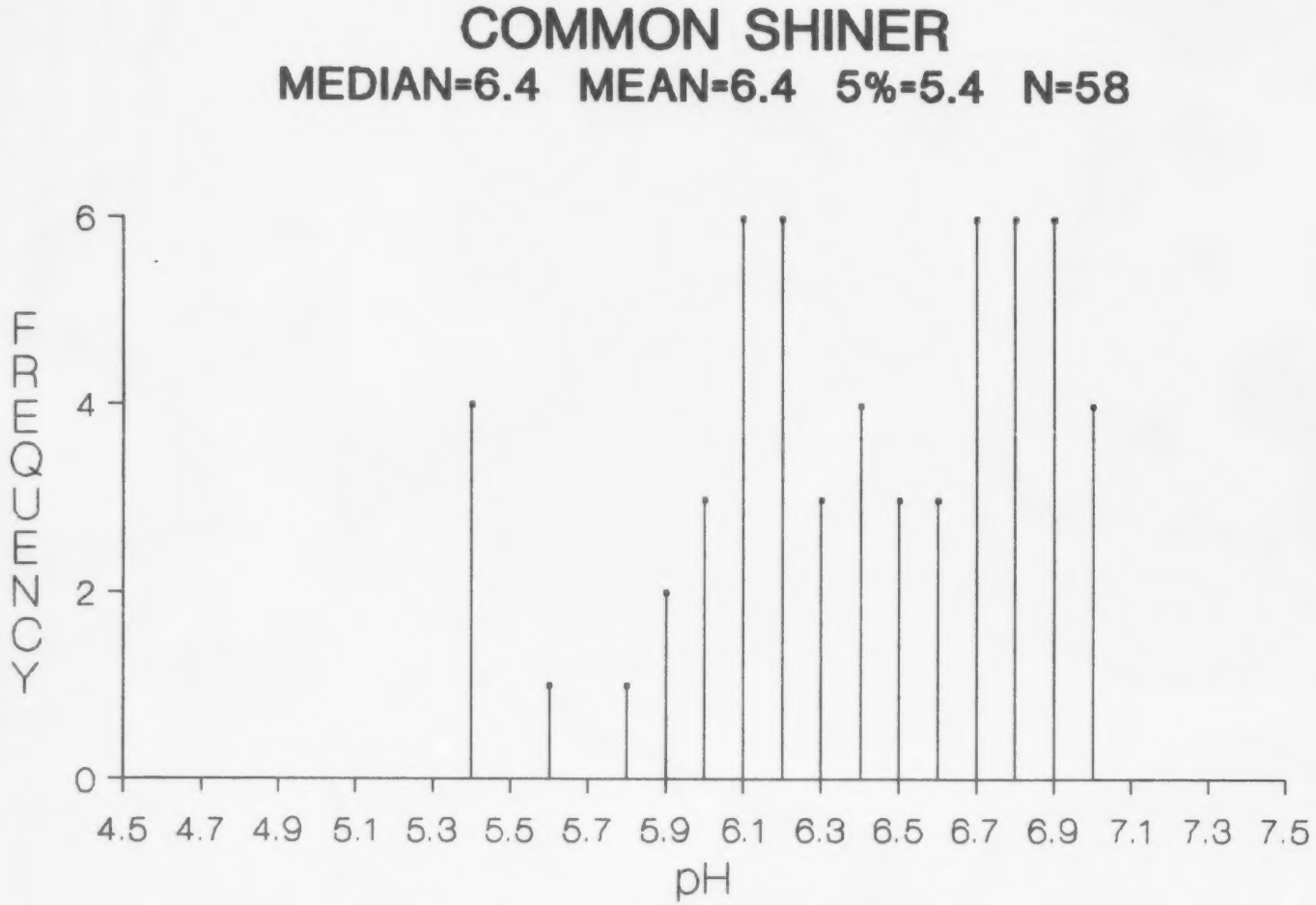


FIGURE 37. pH distribution of acid-sensitive lakes in which the common shiner was found.

# COMMON SHINER

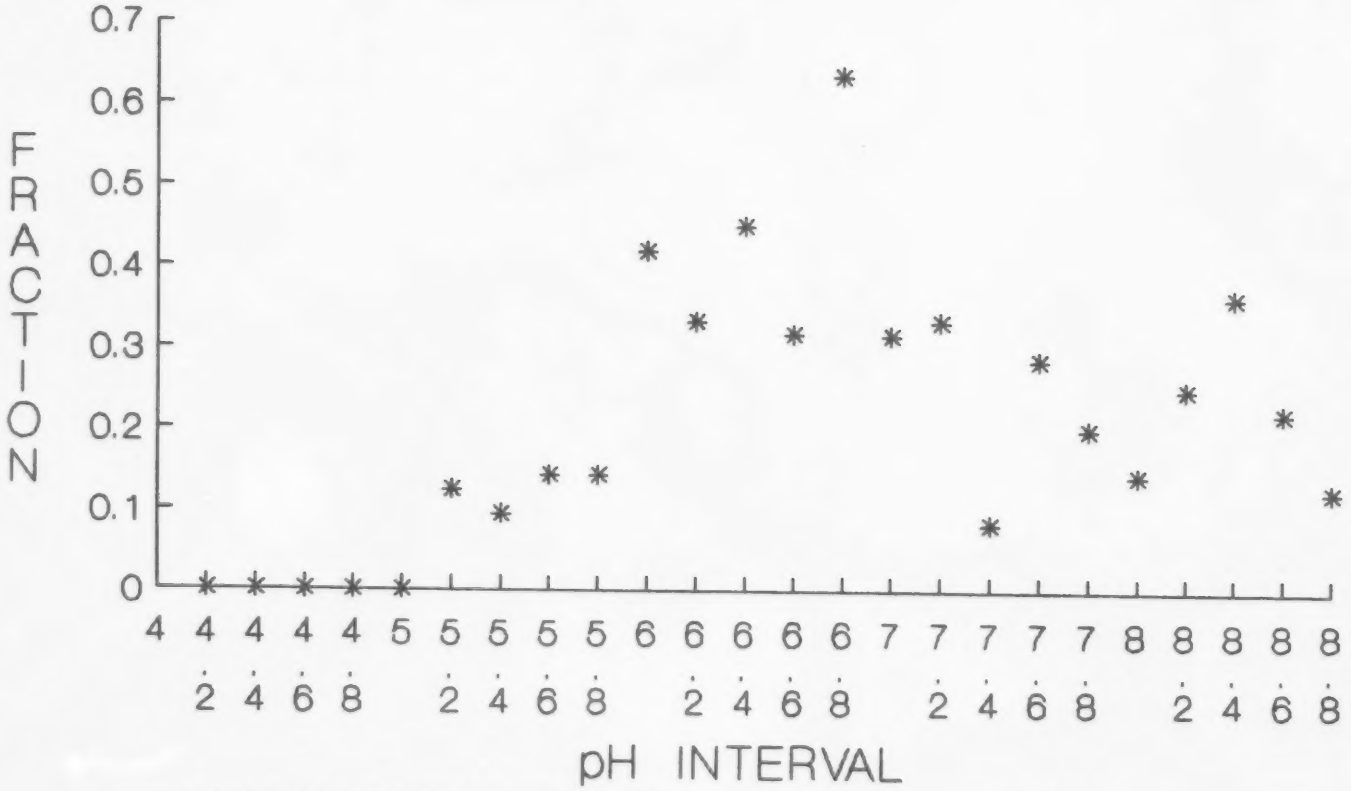


FIGURE 38. Fraction of surveyed lakes in south-central Ontario in which the common shiner was found, by pH interval of 0.2 unit.

LAKE CHUB

The lake chub was found in acid-sensitive lakes mainly in south-central Ontario (Fig. 39). Lakes in which the species was present were significantly larger, with greater maximum and mean depths, and at higher elevations than lakes in which it was absent (Table 12). Lakes with lake chub were less productive (lower MEI) and contained more fish species than lakes without lake chub (Table 12). The species is acid-tolerant, with 37% of inhabited acid-sensitive lakes at pH < 6.0 and a pH threshold for extirpation in the range 4.7 - 5.1 (Fig. 40).

Although the occurrence of lake chub in our surveyed lakes in south-central Ontario fluctuates across the pH gradient, there is a general decline from pH 7.2 to pH 4.4 (Fig. 41).

The lack of an abrupt decline in the occurrence of lake chub at an appropriate pH makes the species unsuitable as an early indicator of changes in the fish community due to acidification.

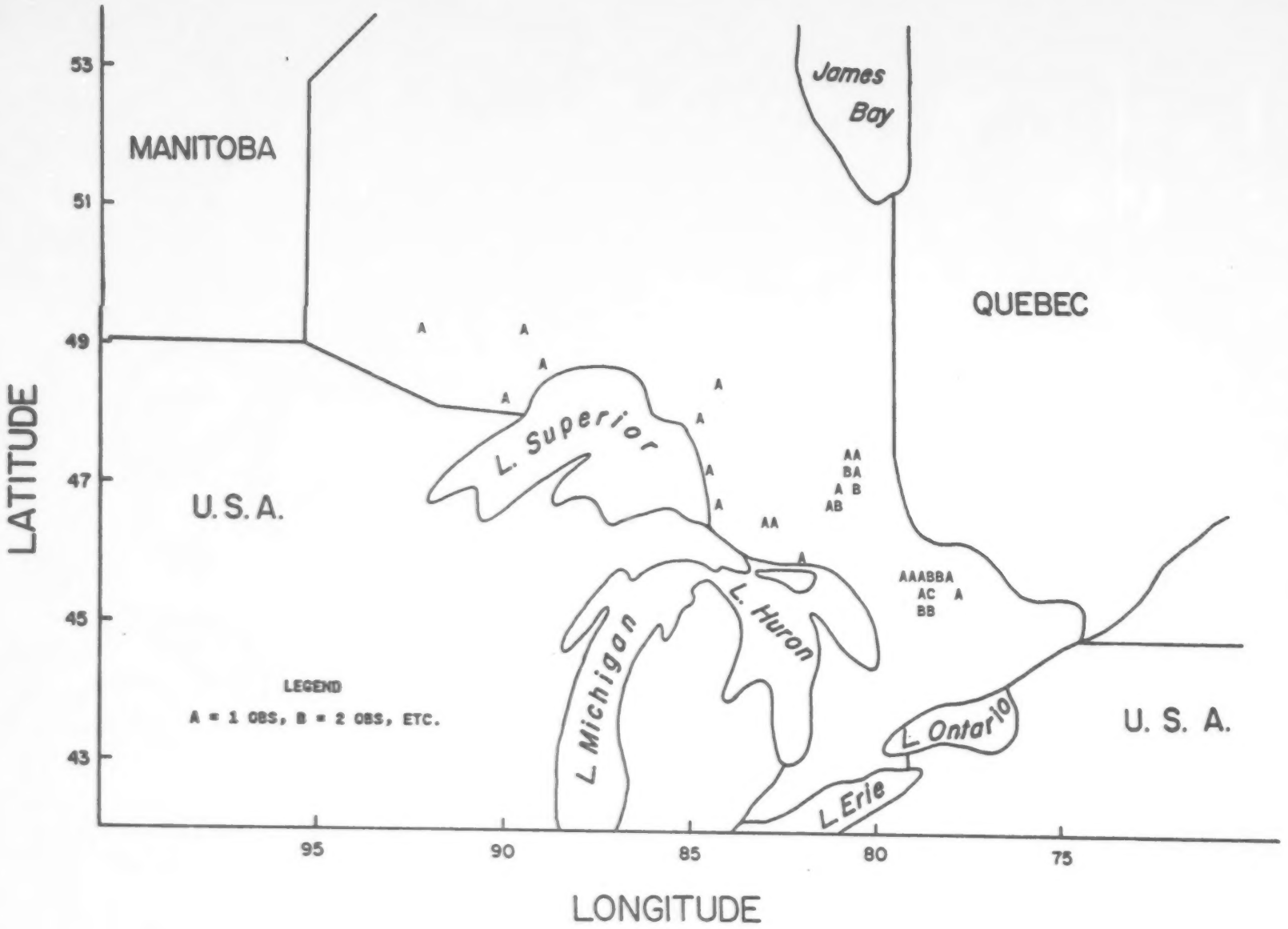


FIGURE 39. Location of acid-sensitive lakes in which the lake chub was found.

Table 12. Differences between the acid-sensitive lakes in south-central Ontario in which the lake chub was present and absent. Significance probabilities are given for T-tests and Wilcoxon rank sum tests. Asterisks indicate variables with significant differences at the 5% level.

| | PRESENT | | | | ABSENT | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Variable | Mean | Median | Range | N | Mean | Median | Range | N | T-Test | Wilcoxon Rank Sum Test |
| pH | 6.0 | 6.1 | 4.7 - 7.1 | 37 | 5.8 | 5.9 | 3.8 - 7.2 | 201 | 0.0630 | 0.1069 |
| Log Alkalinity+5 | 0.84 | 0.80 | 0.58 - 1.15 | 35 | 0.85 | 0.83 | 0.37 - 1.17 | 141 | 0.7211 | 0.7345 |
| SQRT Calcium | 1.63 | 1.67 | 0.44 - 2.51 | 36 | 1.65 | 1.64 | 0.42 - 2.65 | 191 | 0.7879 | 0.7820 |
| Log Aluminum | 1.66 | 1.64 | 0.95 - 2.59 | 34 | 1.82 | 1.88 | 0.00 - 2.87 | 132 | 0.0874 | 0.0651 |
| Log DOC | 0.42 | 0.44 | -0.40 - 0.74 | 28 | 0.39 | 0.41 | -0.22 - 0.99 | 76 | 0.6007 | 0.4954 |
| Latitude | 46.4 | 46.6 | 45.2 - 48.5 | 37 | 46.4 | 46.2 | 44.7 - 47.5 | 201 | 0.6151 | 0.9264 |
| Log Lake Area* | 2.14 | 1.99 | 1.32 - 3.71 | 37 | 1.51 | 1.45 | -0.05 - 3.30 | 194 | 0.0001 | 0.0000 |
| SQRT Max Depth* | 5.73 | 5.45 | 2.24 - 9.35 | 36 | 4.03 | 3.97 | 1.00 - 8.83 | 178 | 0.0001 | 0.0000 |
| SQRT Mean Depth* | 3.26 | 2.90 | 1.26 - 4.93 | 36 | 2.71 | 2.72 | 0.95 - 5.46 | 127 | 0.0011 | 0.0052 |
| Elevation* | 381 | 374 | 238 - 480 | 35 | 328 | 328 | 188 - 534 | 124 | 0.0001 | 0.0084 |
| Log MEI* | 0.40 | 0.40 | -0.10 - 1.26 | 32 | 0.61 | 0.57 | -0.22 - 1.47 | 110 | 0.0018 | 0.0020 |
| SQRT (# Species +1)[a]* | 3.50 | 3.61 | 1.73 - 5.20 | 23 | 3.14 | 3.16 | 1.41 - 4.69 | 45 | 0.0417 | 0.0697 |

[a]in lakes with pH ≥ 6.0

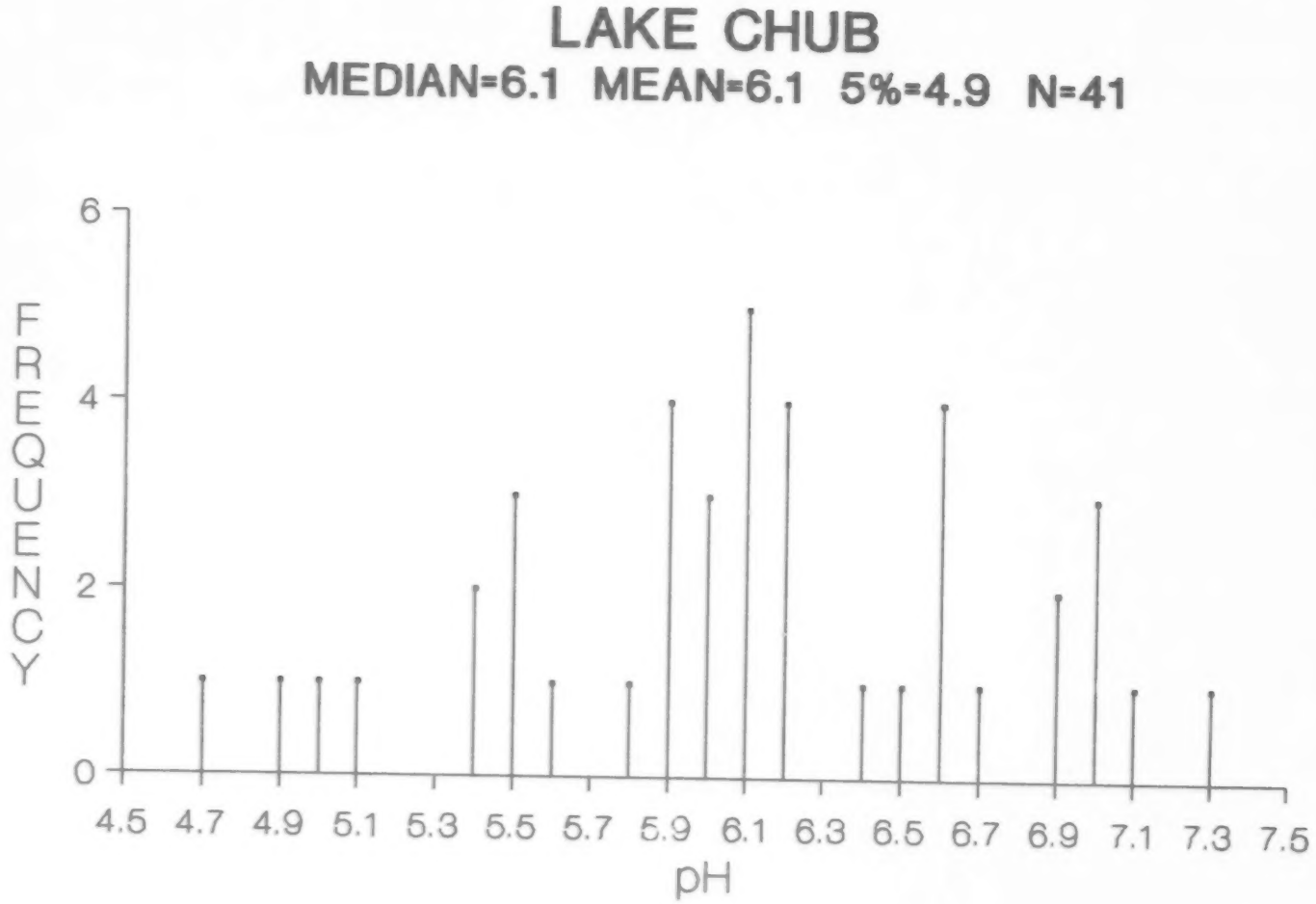


FIGURE 40. pH distribution of acid-sensitive lakes in which the lake chub was found.

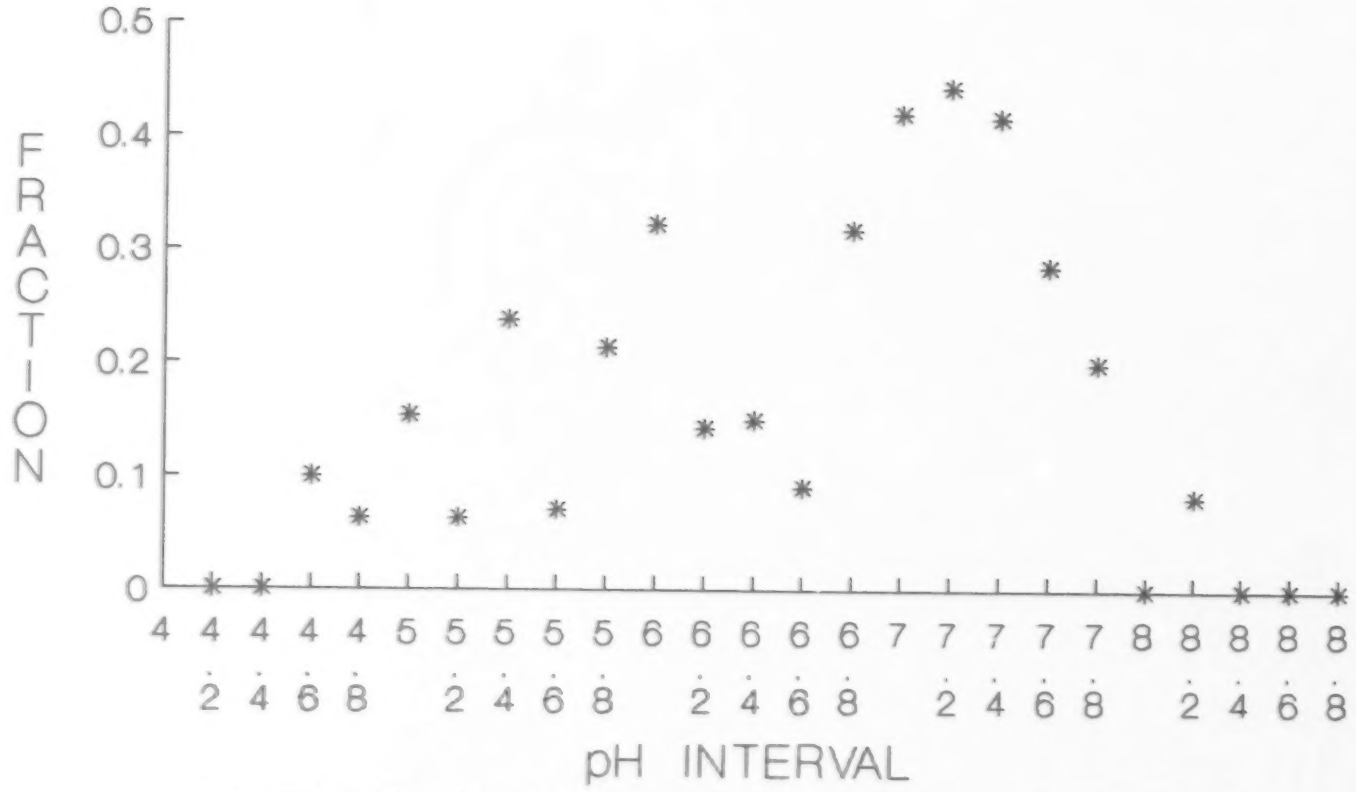


FIGURE 41. Fraction of surveyed lakes in south-central Ontario in which the lake chub was found, by pH interval of 0.2 unit.

BLUNTNOSE MINNOW

The bluntnose minnow was found in acid-sensitive lakes mainly in south-central Ontario (Fig. 42). Lakes in which the species was present were significantly larger, with greater maximum and mean depths than lakes in which it was absent (Table 13). Inhabited lakes had significantly higher values for pH, alkalinity, calcium, and dissolved organic carbon, lower values for aluminum, and were less productive (lower MEI) compared with uninhabited lakes (Table 13). Lakes with bluntnose minnow contained significantly more fish species than lakes without bluntnose minnow (Table 13). The species is moderately sensitive to acidic water, with 15% of inhabited acid-sensitive lakes at pH < 6.0 and a pH threshold for extirpation of about 5.6 (Fig. 43). In a set of 138 lakes in Wisconsin the pH distribution for this species extended to only 6.2 (N = 45) (Rahel and Magnuson 1983), indicating a lower tolerance of acidic conditions than that found in Ontario lakes.

The occurrence of bluntnose minnow in our surveyed lakes in south-central Ontario averages 26% for pH 5.6 - 6.8 and drops abruptly to 0% below pH 5.6 (Fig. 44).

The bluntnose minnow is a good candidate for consideration as an indicator of moderately early changes in the fish community due to acidification in the south-central part of Ontario.

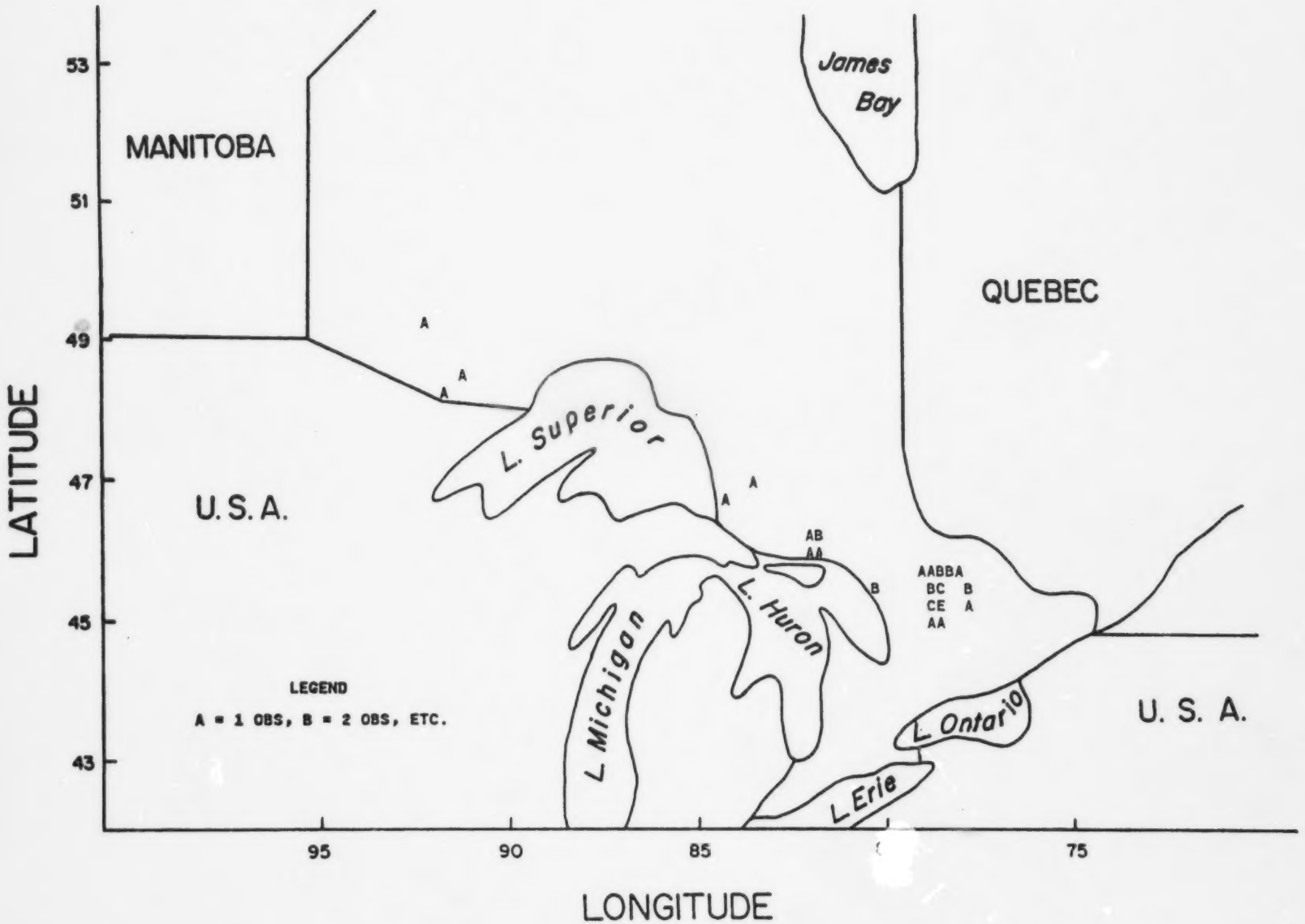


FIGURE 42. Location of acid-sensitive lakes in which the bluntnose minnow was found.

**Table 13. Differences between the acid-sensitive lakes in south-central Ontario in which the bluntnose minnow was present and absent. Significance probabilities are given for T-tests and Wilcoxon rank sum tests. Asterisks indicate variables with significant differences at the 5% level.**

| | PRESENT | | | | ABSENT | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Variable | Mean | Median | Range | N | Mean | Median | Range | N | T-Test | Wilcoxon Rank Sum Test |
| pH* | 6.3 | 6.3 | 5.6 - 7.1 | 37 | 5.7 | 5.7 | 3.8 - 7.2 | 201 | 0.0001 | 0.0000 |
| Log Alkalinity+5* | 0.91 | 0.87 | 0.72 - 1.16 | 28 | 0.84 | 0.81 | 0.37 - 1.17 | 148 | 0.0300 | 0.0119 |
| SQRT Calcium* | 1.81 | 1.73 | 1.41 - 2.61 | 37 | 1.62 | 1.61 | 0.42 - 2.65 | 190 | 0.0009 | 0.0048 |
| Log Aluminum* | 1.39 | 1.32 | 0.95 - 1.86 | 29 | 1.87 | 1.95 | 0.00 - 2.87 | 137 | 0.0001 | 0.0000 |
| Log DOC* | 0.49 | 0.50 | 0.23 - 0.69 | 26 | 0.36 | 0.40 | -0.40 - 0.99 | 78 | 0.0007 | 0.0102 |
| Latitude* | 45.7 | 45.6 | 45.0 - 47.1 | 37 | 46.5 | 46.7 | 44.7 - 48.5 | 201 | 0.0001 | 0.0000 |
| Log Lake Area* | 2.29 | 2.22 | 1.03 - 3.71 | 37 | 1.48 | 1.43 | -0.05 - 3.06 | 194 | 0.0001 | 0.0000 |
| SQRT Max Depth* | 5.77 | 5.97 | 2.00 - 9.35 | 37 | 4.01 | 3.91 | 1.00 - 8.83 | 177 | 0.0001 | 0.0000 |
| SQRT Mean Depth* | 3.30 | 3.39 | 1.10 - 5.22 | 37 | 2.70 | 2.66 | 0.95 - 5.46 | 126 | 0.0002 | 0.0002 |
| Elevation | 347 | 372 | 188 - 480 | 36 | 338 | 354 | 189 - 534 | 123 | 0.6168 | 0.6942 |
| Log MEI* | 0.40 | 0.34 | -0.15 - 1.47 | 36 | 0.62 | 0.61 | -0.22 - 1.45 | 106 | 0.0007 | 0.0001 |
| SQRT (# Species +1)[a]* | 3.68 | 3.74 | 2.45 - 5.20 | 30 | 2.93 | 3.00 | 1.41 - 4.36 | 38 | 0.0001 | 0.0000 |

[a]in lakes with pH ≥ 6.0

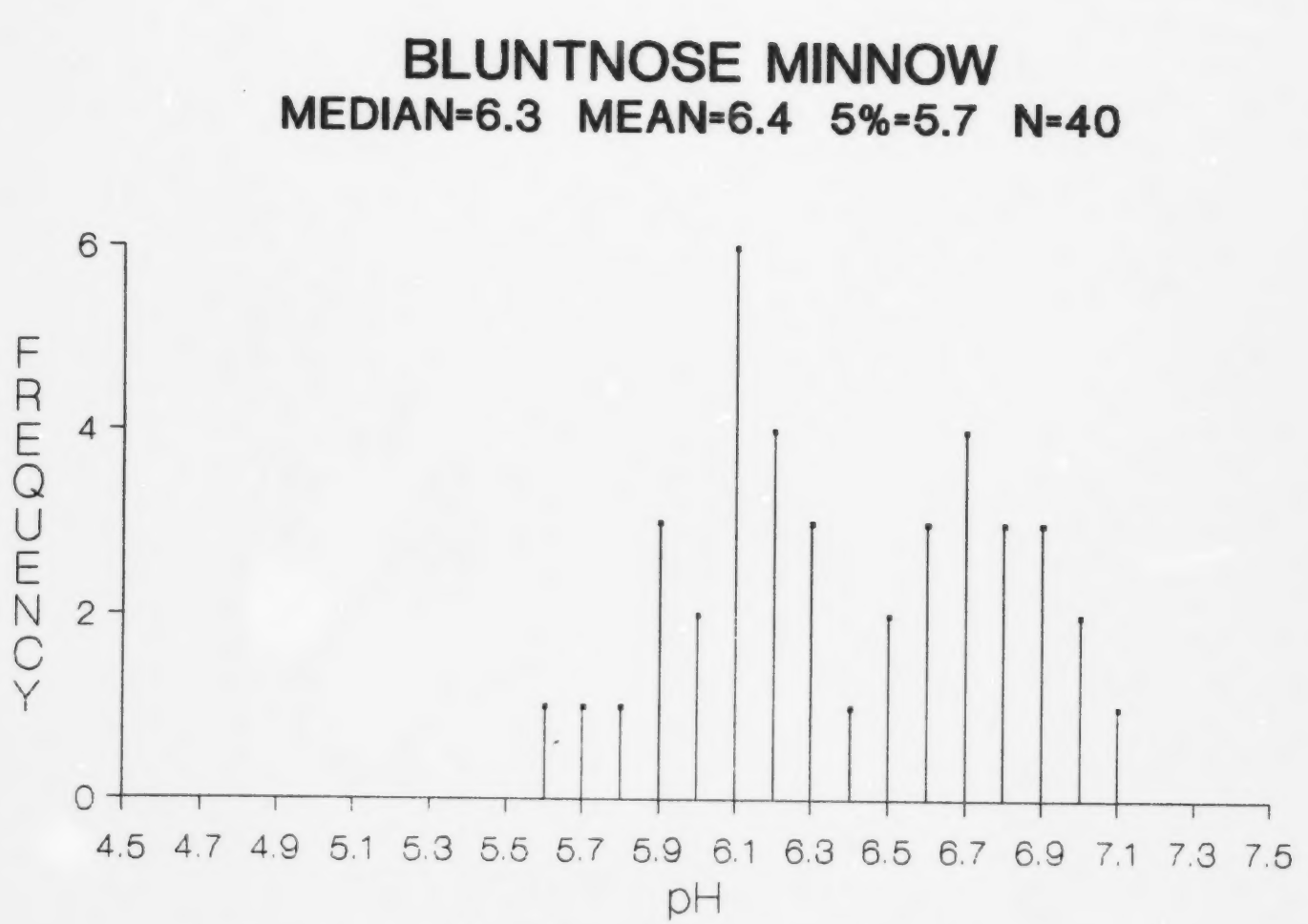


FIGURE 43. pH distribution of acid-sensitive lakes in which the bluntnose minnow was found.

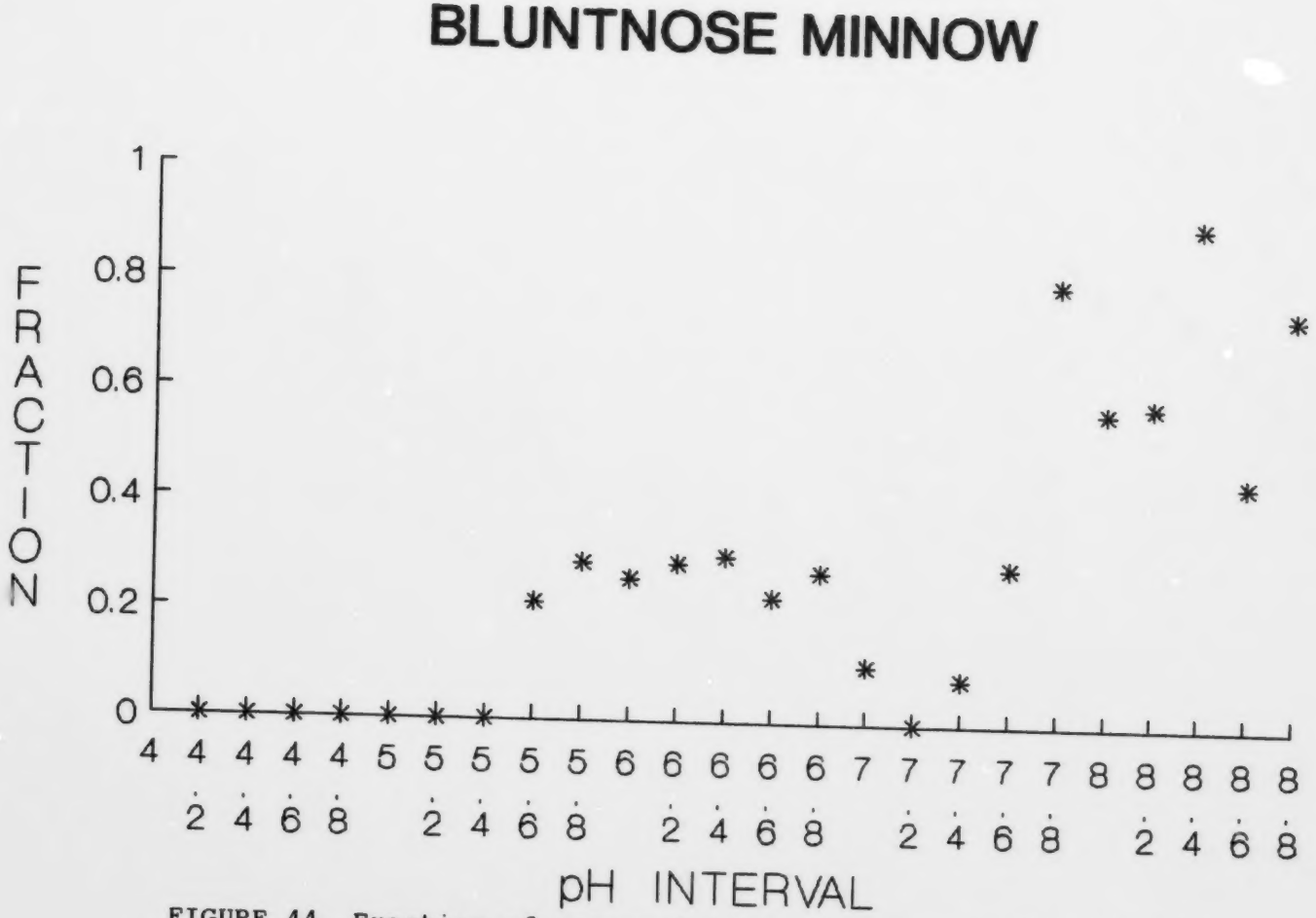


FIGURE 44. Fraction of surveyed lakes in south-central Ontario in which the bluntnose minnow was found, by pH interval of 0.2 unit.

BLACKNOSE SHINER

The blacknose shiner was found in acid-sensitive lakes in both northwestern and south-central Ontario (Fig. 45). However, there was a significantly higher rate of occurrence in the northern latitudes (Table 14). Lakes in which the species was present were significantly larger, with greater maximum and mean depths, and were at higher elevations than lakes in which it was absent (Table 14). Inhabited lakes had significantly higher values for pH, alkalinity, and dissolved organic carbon, lower values for aluminum, and were less productive (lower MEI) than uninhabited lakes (Table 14). The species is acid-sensitive, with only 10% of inhabited acid-sensitive lakes at pH < 6.0 and a pH threshold for extirpation of about 5.8 (Fig. 46). In a set of 138 lakes in Wisconsin the pH distribution for this species extended to only 6.5 (N = 15) (Rahel and Magnuson 1983).

The occurrence of blacknose shiner in our surveyed lakes generally decreases with pH from pH 7.6 to pH 5.4 (Fig. 47). The decline in occurrence at relatively high pH values may be due to a preference for high-pH water and/or the influence of some other factor or factors correlated with pH. The decline at lower pH values (< 5.8) is likely due to adverse population effects associated with low pH.

Although the blacknose shiner appears to be an acid-sensitive species, the lack of a substantial, abrupt decline in its occurrence at an appropriate pH makes the species unsuitable as an early indicator of changes in the fish community due to acidification.

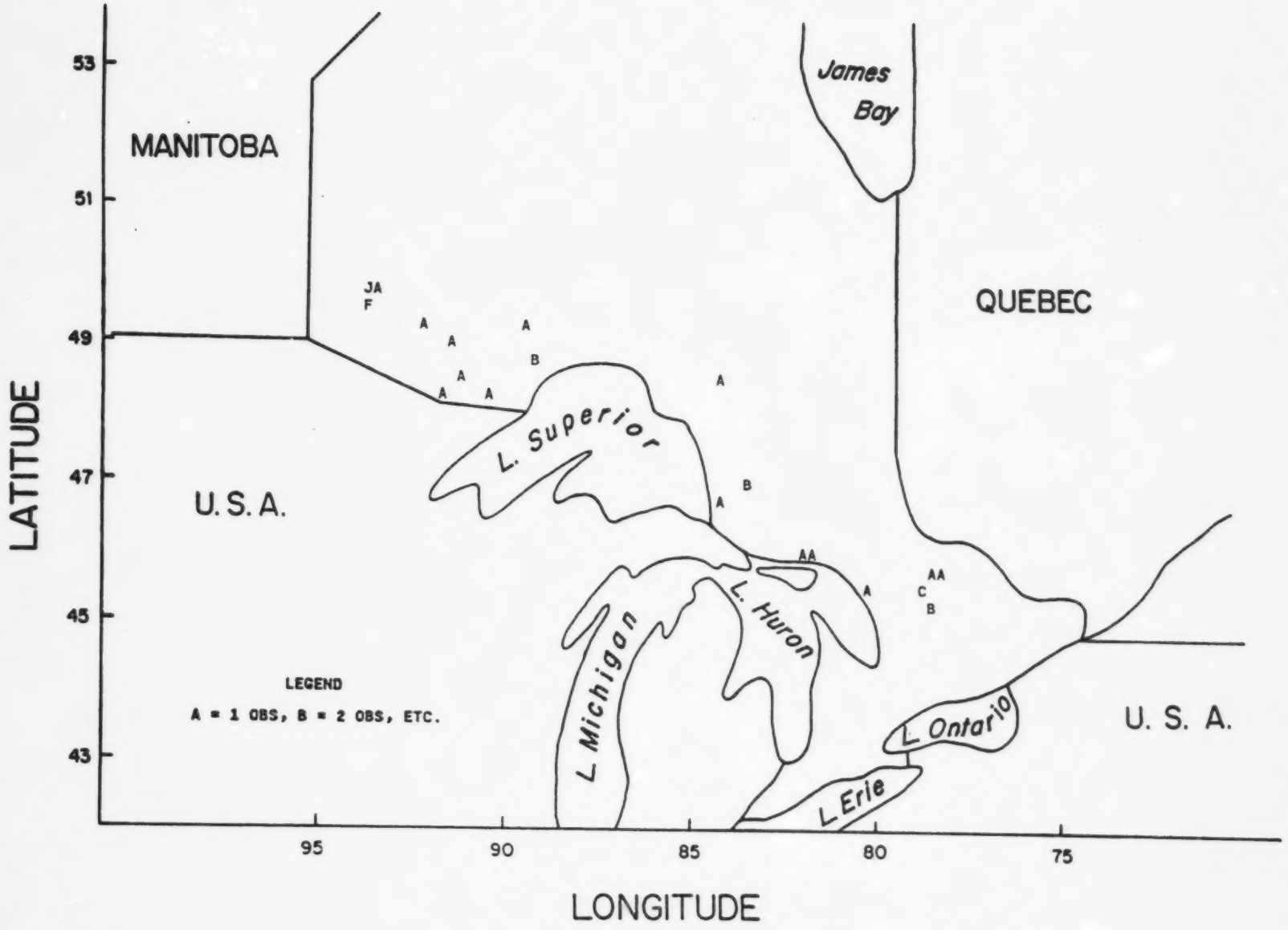


FIGURE 45. Location of acid-sensitive lakes in which the blacknose shiner was found.

**Table 14.** Differences between the acid-sensitive lakes in which the blacknose shiner was present and absent. Significance probabilities are given for T-tests and Wilcoxon rank sum tests. Asterisks indicate variables with significant differences at the 5% level.

| | PRESENT | | | | ABSENT | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Variable | Mean | Median | Range | N | Mean | Median | Range | N | T-Test | Wilcoxon Rank Sum Test |
| pH* | 6.5 | 6.7 | 5.8 - 7.1 | 39 | 5.9 | 6.1 | 3.8 - 7.4 | 293 | 0.0001 | 0.0000 |
| Log Alkalinity+5* | 0.96 | 0.95 | 0.74 - 1.14 | 35 | 0.87 | 0.87 | 0.37 - 1.17 | 227 | 0.0001 | 0.0013 |
| SQRT Calcium | 1.57 | 1.52 | 1.22 - 1.97 | 34 | 1.57 | 1.55 | 0.42 - 2.65 | 279 | 0.9458 | 0.7434 |
| Log Aluminum* | 1.32 | 1.30 | 1.00 - 2.06 | 15 | 1.81 | 1.88 | 0.00 - 2.87 | 156 | 0.0001 | 0.0001 |
| Log DOC* | 0.80 | 0.82 | 0.15 - 1.26 | 30 | 0.61 | 0.59 | -0.40 - 1.33 | 164 | 0.0056 | 0.0051 |
| Latitude* | 48.2 | 49.1 | 45.3 - 49.7 | 39 | 47.1 | 46.8 | 44.7 - 49.8 | 293 | 0.0001 | 0.0042 |
| Log Lake Area* | 1.74 | 1.75 | 0.28 - 3.81 | 37 | 1.46 | 1.41 | -0.05 - 3.71 | 285 | 0.0259 | 0.0688 |
| SQRT Max Depth* | 5.51 | 5.90 | 1.45 - 8.64 | 20 | 4.23 | 4.21 | 1.00 - 9.35 | 203 | 0.0031 | 0.0019 |
| SQRT Mean Depth* | 3.24 | 3.42 | 1.87 - 4.57 | 19 | 2.78 | 2.72 | 0.84 - 5.46 | 153 | 0.0335 | 0.0192 |
| Elevation* | 389 | 409 | 213 - 503 | 18 | 340 | 357 | 188 - 534 | 150 | 0.0398 | 0.0335 |
| Log MEI* | 0.31 | 0.28 | -0.15 - 0.77 | 18 | 0.59 | 0.57 | -0.22 - 1.47 | 133 | 0.0013 | 0.0009 |
| SQRT (# Species +1)[a] | 3.07 | 2.83 | 1.73 - 4.90 | 34 | 2.71 | 2.65 | 1.00 - 5.20 | 107 | 0.0383 | 0.1156 |

[a] in lakes with pH ≥ 6.0

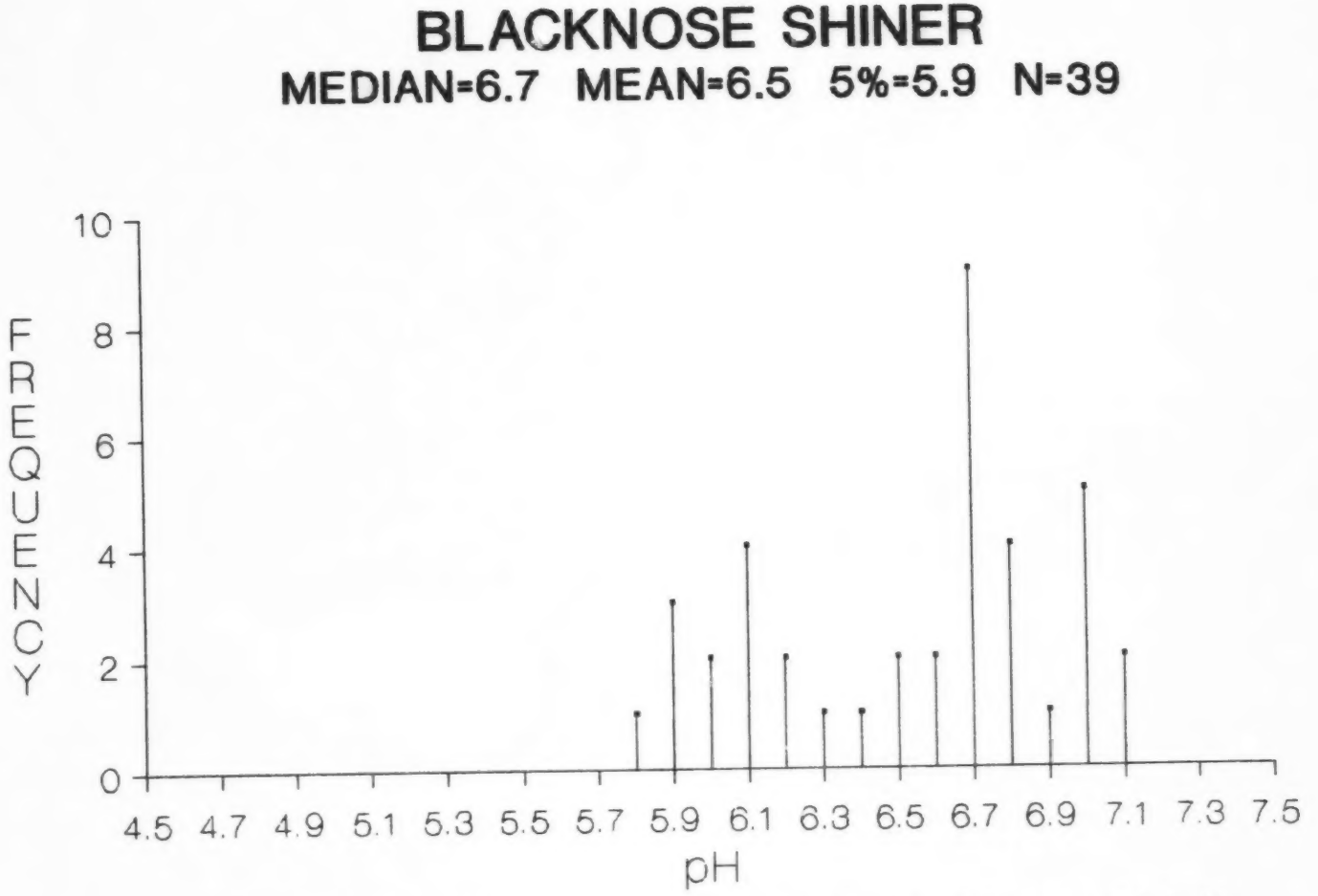


FIGURE 46. pH distribution of acid-sensitive lakes in which the blacknose shiner was found.

# BLACKNOSE SHINER

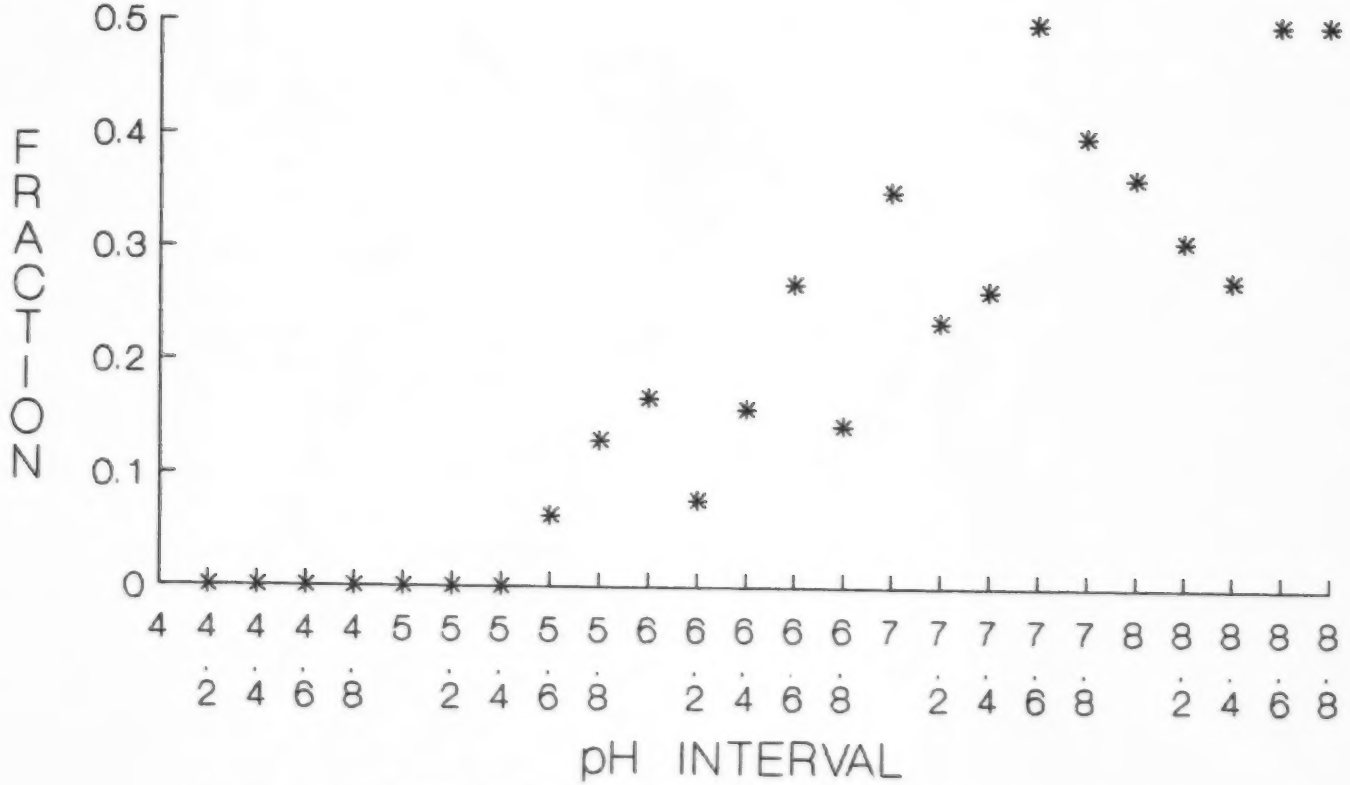


FIGURE 47. Fraction of surveyed lakes in which the blacknose shiner was found, by pH interval of 0.2 unit.

SLIMY SCULPIN

The slimy sculpin was found in acid-sensitive lakes almost exclusively in northwestern Ontario (Experimental Lakes Area) (Fig. 48). Lakes in which the species was present were larger and contained more species of fish than lakes in which it was absent (Table 15). Inhabited lakes had higher values for pH, alkalinity, and calcium, and lower values for dissolved organic carbon compared with uninhabited lakes (Table 15). The species appears to be very acid-sensitive, with only 3 inhabited acid-sensitive lakes with pH < 6.4 and a pH threshold for extirpation in the range 5.8 - 6.4 (Fig. 49). In experimentally acidified Lake 223, Mills et al. (1987) found the threshold for recruitment failure for the species occurred between pH 5.6 and 5.9.

The occurrence of slimy sculpin in our surveyed lakes in northwestern Ontario drops sharply from an average 28% for pH 6.4 - 7.8 to 0% at pH 6.2 and 6.0 (Fig.50). Although occurrence is relatively high at pH 5.8 (22%), the species was only found in 2 of the 25 lakes with pH in the range 5.8 - <6.4. More data from low pH lakes in northwestern Ontario are needed to confirm the apparent high sensitivity of the slimy sculpin to acidic water.

Our data suggest that the slimy sculpin may be a useful indicator of early changes in the fish community due to acidification in the northwestern part of the province.

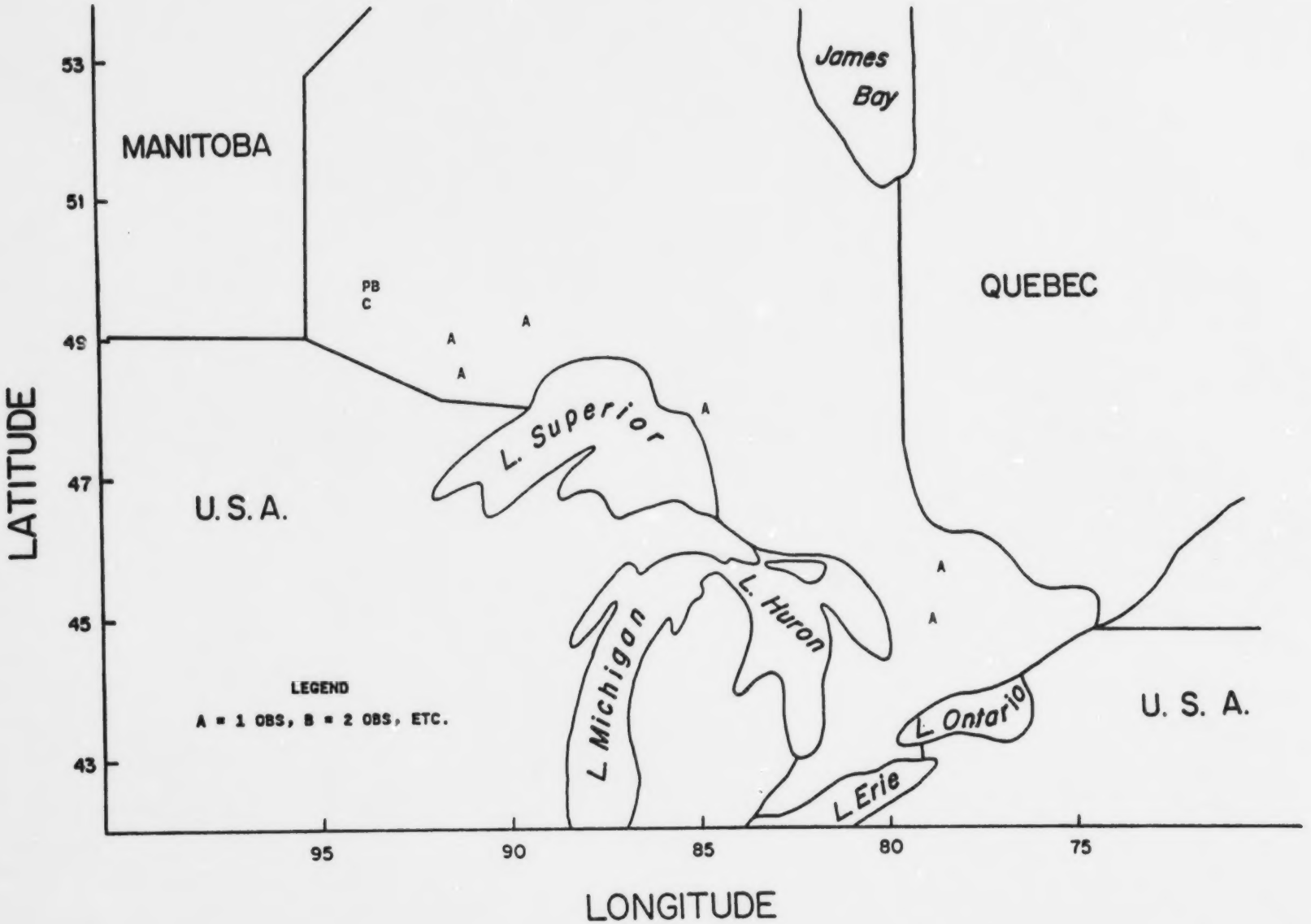


FIGURE 48. Location of acid-sensitive lakes in which the slimy sculpin was found.

Table 15. Differences between the acid-sensitive lakes in northwestern Ontario in which the slimy sculpin was present and absent. Significance probabilities are given for T-tests and Wilcoxon rank sum tests. Asterisks indicate variables with significant differences at the 5% level.

| | PRESENT | | | | ABSENT | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Variable | Mean | Median | Range | N | Mean | Median | Range | N | T-Test | Wilcoxon Rank Sum Test |
| pH* | 6.7 | 6.7 | 5.8 - 7.4 | 24 | 6.3 | 6.4 | 4.8 - 7.3 | 70 | 0.0002 | 0.0006 |
| Log Alkalinity+5* | 0.99 | 1.00 | 0.88 - 1.12 | 22 | 0.93 | 0.93 | 0.72 - 1.16 | 64 | 0.0006 | 0.0017 |
| SQRT Calcium* | 1.47 | 1.48 | 1.22 - 1.82 | 23 | 1.31 | 1.26 | 0.89 - 2.00 | 63 | 0.0011 | 0.0003 |
| Log Aluminum | 1.15 | 1.15 | 1.00 - 1.30 | 2 | 1.17 | 1.20 | 1.00 - 1.30 | 3 | | |
| Log DOC* | 0.81 | 0.83 | 0.53 - 1.01 | 22 | 0.96 | 0.99 | 0.04 - 1.33 | 68 | 0.0015 | 0.0003 |
| Latitude | 49.6 | 49.7 | 48.6 - 49.7 | 24 | 49.5 | 49.6 | 48.2 - 49.8 | 70 | 0.2041 | 0.1371 |
| Log Lake Area* | 1.76 | 1.64 | 0.76 - 3.81 | 23 | 1.00 | 0.83 | 0.00 - 3.20 | 68 | 0.0001 | 0.0000 |
| SQRT Max Depth | 7.33 | 7.33 | 6.02 - 8.64 | 2 | 4.38 | 4.38 | 1.34 - 6.20 | 7 | | |
| SQRT Mean Depth | 3.78 | 3.78 | 3.36 - 4.21 | 2 | 2.45 | 2.37 | 0.84 - 3.56 | 7 | | |
| Elevation | 424 | 424 | 408 - 439 | 2 | 448 | 458 | 389 - 503 | 7 | | |
| Log MEI | 0.12 | 0.12 | -0.15 - 0.40 | 2 | 0.60 | 0.65 | 0.00 - 1.36 | 7 | | |
| SQRT (# Species +1)[a]* | 2.90 | 2.83 | 2.24 - 4.90 | 22 | 2.13 | 2.00 | 1.00 - 4.90 | 51 | 0.0001 | 0.0000 |

[a]in lakes with pH ≥ 6.0

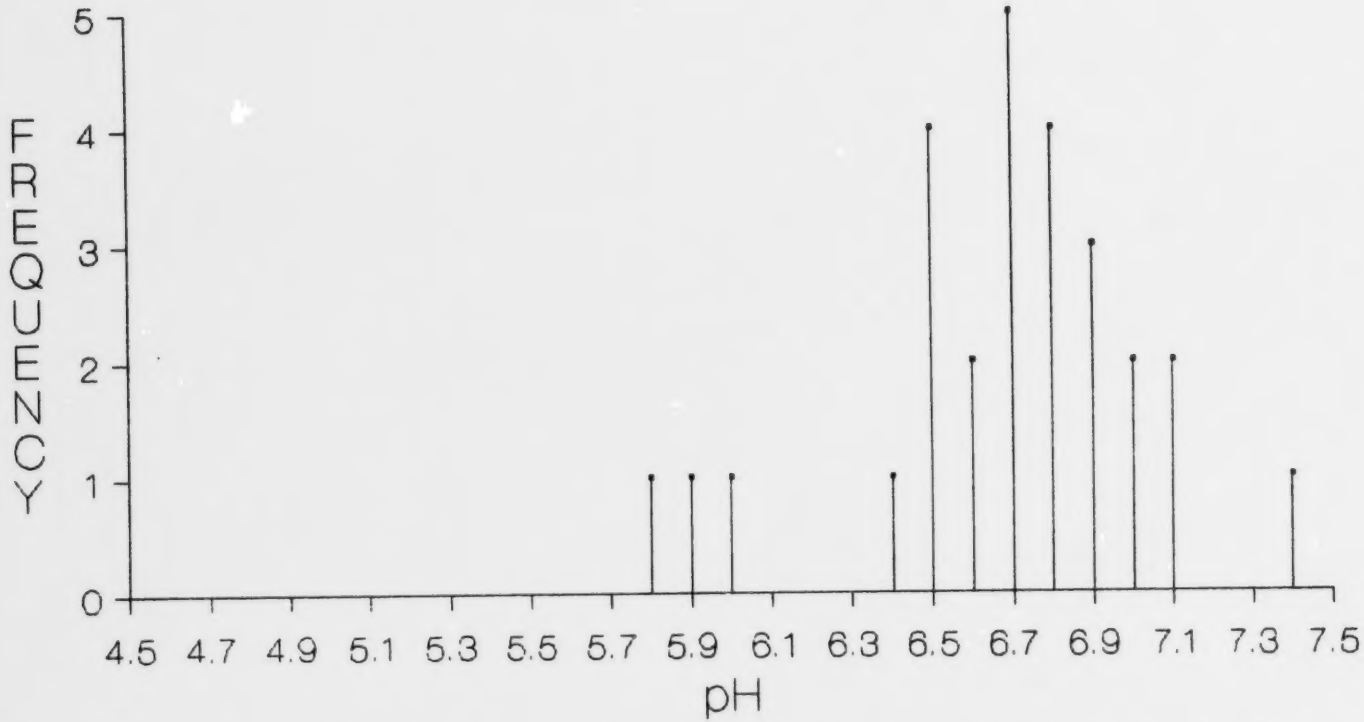


FIGURE 49. pH distribution of acid-sensitive lakes in which the slimy sculpin was found.

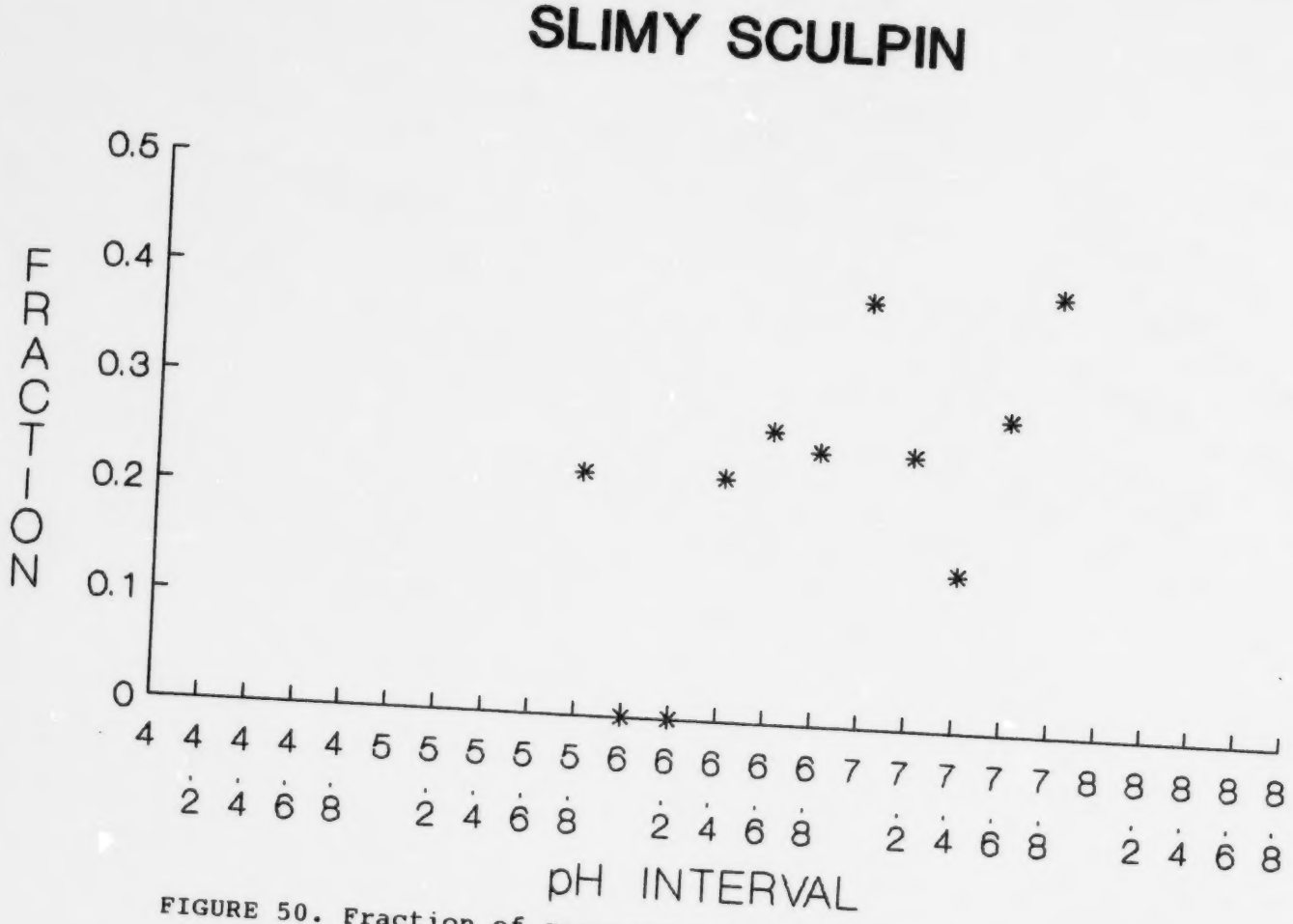


FIGURE 50. Fraction of surveyed lakes in northwestern Ontario in which the slimy sculpin was found, by pH interval of 0.2 unit.

## SUMMARY

Of the 13 most common small fish species found in our set of acid-sensitive lakes (alkalinity < 10 mg/l), five species were assessed as potentially useful indicators of early changes in the fish community due to acidification: slimy sculpin, blacknose shiner, fathead minnow, common shiner, and bluntnose minnow (Table 16). Populations of these species are expected to signal changes by decreasing in abundance and disappearing. However, populations of the more acid-tolerant species, such as the pearl dace, may signal early changes by increasing in abundance.

In general, the number of species of cyprinids, which represent most of the small species in Ontario, decreases with decreasing pH below pH 6.0, similar to the total number of species. However, the number of cyprinid species appears to be relatively independent of lake size, in contrast to the total number of fish species. As a result, the ratio of cyprinid species to total species increases with decreasing lake size. When lake size is taken into account, both cyprinids and other, larger species initially contribute similar proportions to the reduction in total species number with pH. Therefore, just below pH 6.0, there is little change in the ratio of cyprinid species number to total species number. However, at lower pH values the reduction in the number of cyprinid species is

proportionately greater than that for other species, and the ratio of cyprinid species number to total species number decreases.

**Table 16. The 13 most common small fish species found in acid-sensitive lakes in Ontario listed by estimated pH threshold for extirpation. Suitability as an indicator of early changes in the fish community due to acidification is also given.**

| Species | pH Threshold For Extirpation | Suitability as Indicator Species |
|---|---|---|
| Slimy Sculpin | 5.8 - 6.4 | FAIR - Restricted to Northwestern Ontario |
| Blacknose Shiner | 5.8 | FAIR - Low Occurrence |
| Fathead Minnow | 5.5 - 5.8 | GOOD |
| Common Shiner | 5.4 - 5.8 | GOOD - Restricted to South-central Ontario |
| Bluntnose Minnow | 5.6 | FAIR - Restricted to South-central Ontario |
| Iowa Darter | 5.4 | POOR |
| Finescale Dace | 5.4 | POOR |
| Brook Stickleback | 5.1 - 5.3 | POOR |
| Creek Chub | 5.0 - 5.2 | POOR |
| Pearl Dace | 4.7 - 5.2 | POOR - Possible Increase in Abundance |
| Lake Chub | 4.7 - 5.1 | POOR |
| Northern Redbelly Dace | 5.0 | POOR |
| Golden Shiner | 4.7 - 4.9 | POOR - Possible Increase in Abundance |

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